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Tractors and Automobiles

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Preface

Tractors and automobiles are the main power means that help mechanize farming and the transportation of various goods.

These vehicles are the fruit of a laborious, purposeful quest by several generations of gifted people.

Russian inventors and engineers were among the first in the world to mark the beginning of the development of off-track vehicles and cross-country prime movers to replace draft animals in farm work.

To use tractors and automobiles with a maximum efficiency, the driver-mechanic must know their design in detail, service them timely and at a high standard of workmanship, and rectify in due course any faults they develop during operation.

This book describes the design of modern tractors and automobiles without reference to particular models. Sections I, III, and IV are written by V. Rodichev and Section II, by G. Rodicheva.

Part I
GENERAL INFORMATION

Chapter 1
General Design of Tractors and Automobiles

1.1. Classification of Automobiles and Tractors

The AUTOMOBILE (car or truck) is a self-propelled (motor) vehicle intended for transporting goods and/or people and for carrying out special tasks.

AS TO PURPOSE, motor vehicles are divided into transport vehicles, special-purpose vehicles, and competition vehicles.

Transport vehicles are classed in several types:

(a) cars – motor vehicles intended for carrying small groups of people (up to eight in number);

(b) buses – passenger service vehicles designed for carrying large groups of people (more than eight in number);

(c) trucks – motor vehicles intended for carrying various cargos.

According to cargo (load-carrying) capacity, trucks are in turn divided into the following classes: pick-up trucks (up to 0.5 t), light trucks (from 1 to 2 t), medium trucks (from 2 to 5 t), heavy trucks (from 5 to 15 t), and overweight trucks (more than 15 t).

Trucks used to carry loose and sticky goods are equipped with tipping bodies and are referred to as dump trucks.

Special-purpose vehicles, as their name implies, are intended for special work and are equipped accordingly. This group includes truck cranes, tank trucks, seed-filler trucks, etc. These are modifications of standard transport vehicle models.

Competition vehicles are cars specially designed for racing.

AS TO THE TYPE OF CHASSIS, motor vehicles may be either framed or frameless.

Framed vehicles have a support structure, called frame, to which all the component parts of the vehicle are attached.

Frameless (unit-construction) vehicles have no frame, and all their component parts are attached directly to the vehicle body. The body in this case is referred to as unitized.

AS TO THE PRIME MOVER, automobiles may be powered by carburettor engines, diesel engines, or electric motors.

Carburettor engines operate mainly on gasoline (petrol), diesel engines run on diesel fuel, and electric motors are supplied from storage batteries. Accordingly, automobiles are divided into gasoline-powered, diesel-powered, and battery-powered types.

The TRACTOR is a wheeled or tracked self-propelled vehicle used as a power means for moving agricultural, road-building, and other machines equipped with special tools, and also for towing trailers. The tractor engine can be used as a prime mover for active (moving) tools or stationary farm machinery through the intermediary of the power takeoff (PTO) shaft or belt pulley.

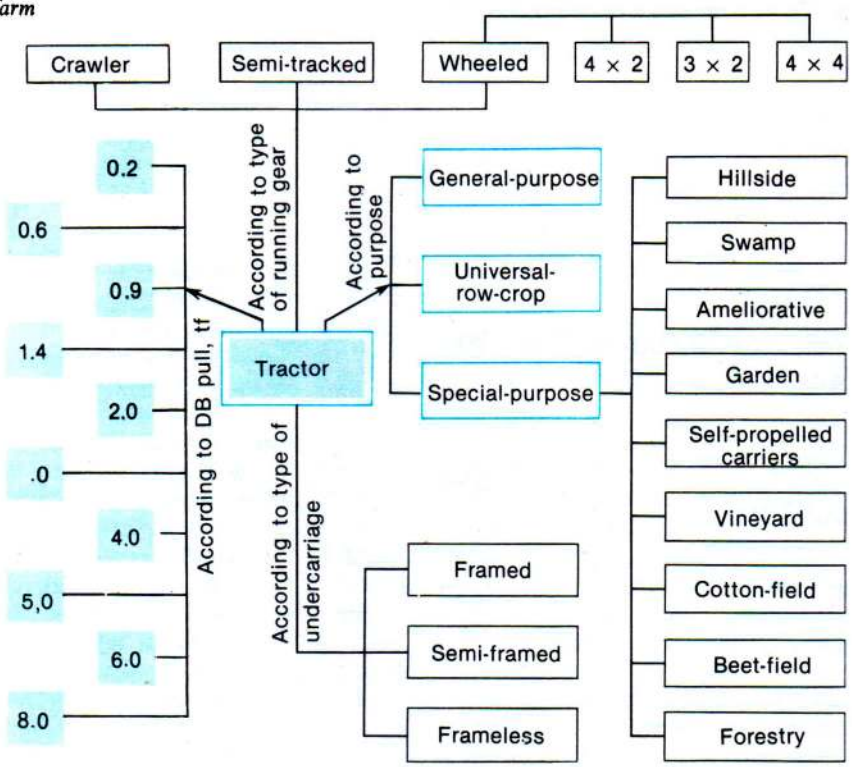
The uses of the tractor in agriculture are many, and so different types of tractor are needed to do different types of farm work.

Farm tractors are classified as follows (Fig. 1).

AS TO PURPOSE, modern farm tractors are

1

Classification of farm tractors



classed in three groups: general-purpose (land utility) tractors, universal-row-crop (row-crop utility) tractors, and special-purpose tractors.

Land utility tractors are used for major farm operations common to the cultivation of most crops, such as tillage, discing, general cultivations, harrowing, sowing, and harvesting. The tractors are characterized by a low ground clearance, increased engine power, and good traction, thanks to their wide tires or tracks enabling them to develop a high pull.

Universal-row-crop tractors are intended for row-crop work, as well as for many other field tasks. For this purpose, some row-crop utility tractors are provided with replaceable driving wheels of different tread widths – wide for general farm work and narrow for row-crop work. In order not to damage plants, the tractors have a high ground clearance and a wide wheel track that can be adjusted to suit the particular inter-row distance.

Special-purpose tractors are modifications of standard land or row-crop utility tractor models and are used for definite jobs (e. g., in vineyards, cotton fields) or for various jobs under certain conditions (e. g., on marshy soils, hillsides). Thus, special tractors used to mechanize the cultivation of cotton have a single front (steerable) wheel, swamp tractors are equipped with wide tracks enabling them to operate on marshy soils, and hilliside tractors are designed to work on hillsides sloping at up to 16°.

AS TO THE DESIGN OF THE RUNNING GEAR, tractors are divided into crawler (track-laying) and wheeled types.

Crawler tractors are distinguished by a large ground contact area and therefore have a good

track adhesion; they crush and compact the soil insignificantly. Such tractors show a high cross-country power and are capable of developing a high pull.

Wheeled tractors are more versatile and can be used for both field and transport work, but their traction is lower than that of crawler tractors.

AS TO THE TYPE OF UNDERCARRIAGE, tractors may be *framed, semi-framed* or *frameless*. The body of framed tractors is essentially a riveted or welded frame, that of semi-framed tractors is made up of two short longitudinal beams (side members) bolted or welded to the rear axle housing, while in frameless tractors, the body is formed by bolting together the casings of individual tractor mechanisms.

AS TO THE NOMINAL DRAWBAR (DB) pull, tractors are divided into *several classes* differing in design.

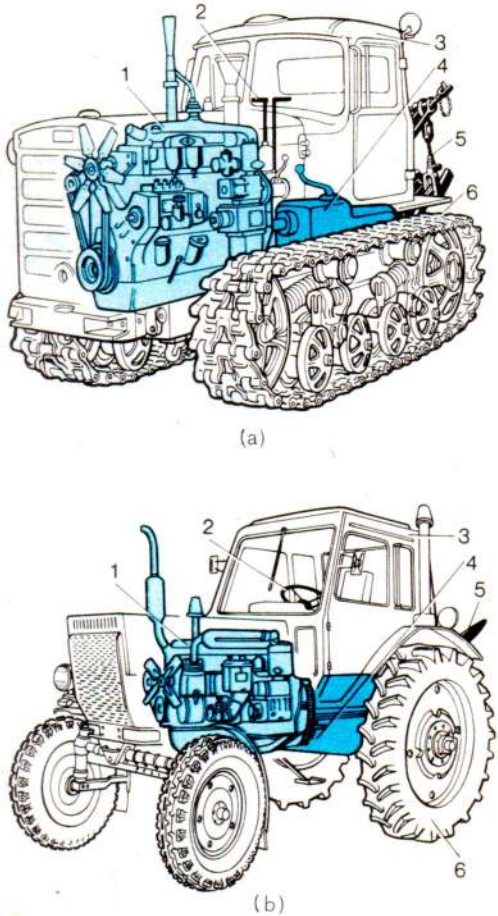
1.2. Main Component Parts of Tractor and Automobile

Both the tractor and the automobile are complex self-propelled machines consisting of separate interacting mechanisms and units that can be combined into certain groups.

The arrangement of the main component parts (groups of mechanisms) of the tractor is shown in Fig. 2. Irrespective of particular design features, all tractors consist of engine *1*, drive line *4*, running gear *6*, steering mechanism *2*, working attachments *5*, and auxiliary equipment *3*.

THE ENGINE converts thermal energy into mechanical energy.

THE DRIVE LINE comprises a set of mechanisms which transmit the torque* developed by the engine to the driving wheels or tracks and change the driving torque both in magnitude and direction. The drive line includes the clutch, flexible coupling, transmission (gearbox) and rear axle.



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Arrangement of the main component parts of the tractor

(a) crawler tractor;
(b) wheeled tractor;
1 – engine;
2 – steering mechanism;
3 – auxiliary equipment;
4 – drive line;
5 – working (live) attachments;
6 – running gear

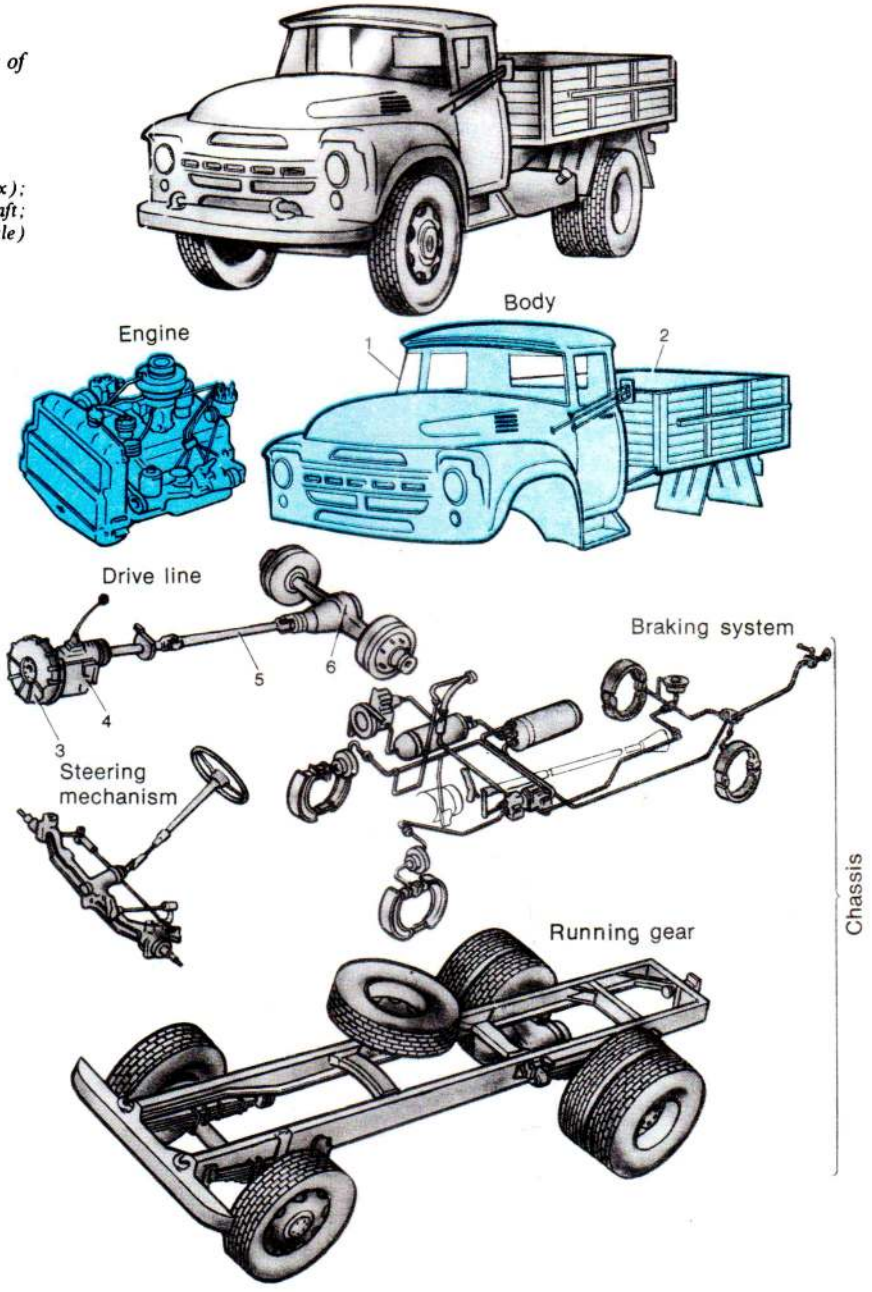
The clutch serves to disconnect the engine shaft from the transmission for a short period of time while the driver is shifting gears and also to connect smoothly the flow of power from the

* Torque is a moment of force which tends to produce rotation of a body. It is measured by multiplying the magnitude of the force by its arm, i.e., the perpendicular distance from the line of action of the force to the axis of rotation.

3

Main component parts of the automobile

1 – driver's cab;
2 – cargo body;
3 – clutch;
4 – transmission (gearbox);
5 – propeller (cardan) shaft;
6 – final drive (driving axle)



engine to the driving wheels or tracks when starting the tractor from rest.

The flexible coupling incorporates elastic elements allowing to connect the clutch shaft and the transmission drive shaft with a slight misalignment.

The transmission makes it possible to change the driving torque and the running speed of the tractor by engaging different pairs of gears. With the direction of rotation of the engine shaft remaining the same, the transmission enables the tractor to be put in reverse.

The rear-axle mechanisms increase the driving torgue and transmit it to the driving wheels or tracks at right angles to the drive shaft. In most tractors, the rear axle also comprises brakes.

In the wheeled tractor, as distinct from its crawler counterpart, the drive line includes the differential which enables the driving wheels to revolve with different speeds when making turns or running over a ragged terrain, at which time the left- and right-hand wheels must travel different distances during one and the same time.

THE RUNNING GEAR is needed for the tractor to move. The rotation of the driving wheels (or the movement of the tracks) in contact with the ground is converted into the translatory motion of the tractor.

THE STEERING MECHANISM serves to change the direction of movement of the tractor by turning its front wheels (in wheeled tractors) or by varying the speed of one of the tracks (in crawler tractors).

THE WORKING ATTACHMENTS of the tractor are used to utilize the useful power of the tractor engine for various farm tasks. They include the power takeoff shaft, drawbar (hitch device), implement-attaching (mounting) system, and belt pulley.

THE TRACTOR AUXILIARIES include the driver's cab with a spring-mounted seat and heating and ventilation equipment, hood, lighting equipment, tell tales (indicators), horns, etc.

The arrangement and purpose of the main component parts of the automobile (Fig. 3) are in principle the same as those of the wheeled tractor. In the automobile, the drive line, running gear, steering mechanism, and braking system are referred to collectively as the chassis. The steering mechanism serves to change the direction of travel and the braking system, to slow down the running speed of the automobile or to stop it.

The auxiliaries of the automobile include a winch, cab heating and ventilation equipment, hitch bar, etc.

Review Questions

1. What is the purpose of the automobile and tractor?
2. According to which features are tractors and automobiles classified?
3. How are tractors and automobiles distinguished according to purpose?
4. What are the main component parts of the tractor?
5. Name the main component parts of the automobile.
6. What is the purpose of the engine?
7. What are the mechanisms the drive line of the automobile consists of?

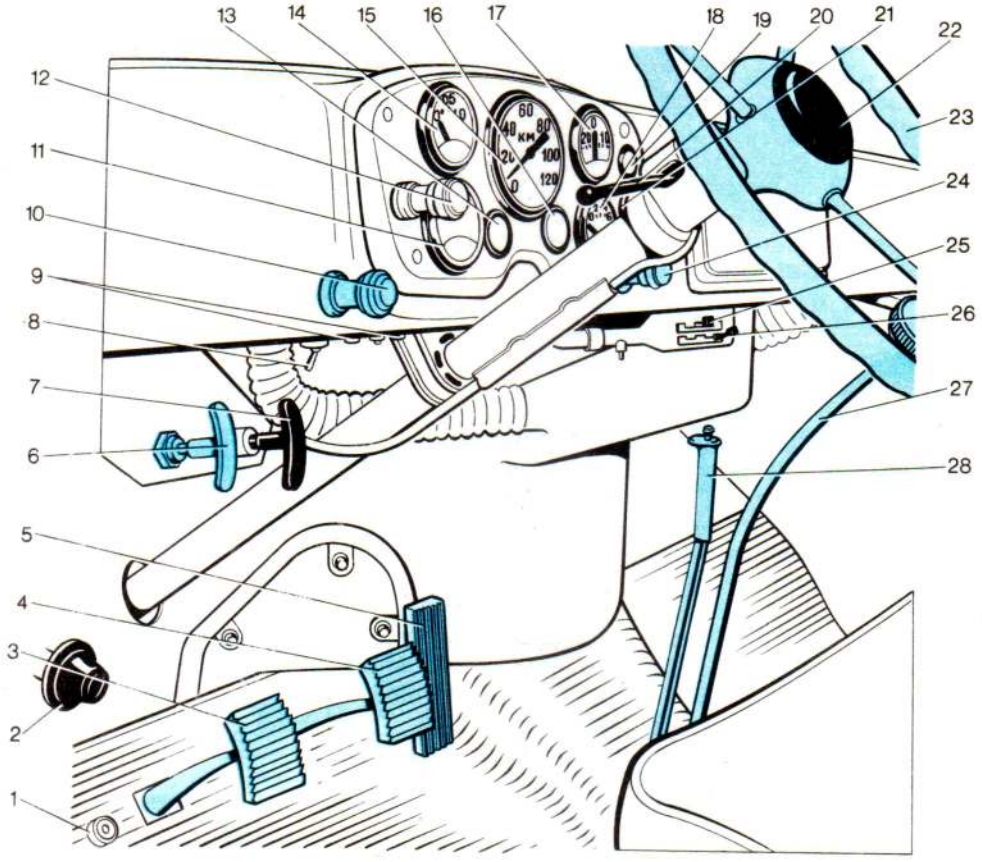
Chapter 2

Control of the Tractor and the Automobile

2.1. Automobile Controls

The automobile and its engine are controlled and the operation of their mechanisms is monitored by means of controls and instruments located in the cab in front of the driver's seat (Fig. 4).

TO START THE ENGINE and control its operation, use is made of throttle (accelerator, or gas) pedal *5*, radiator shutter control handle *6*, choke button *10*, ignition/starter switch *21*, and throttle hand lever *24*. The ignition/starter switch is operated by a key which may be



4

Controls of the ГАЗ-53А Model truck

1 – foot dimmer (beam selector) switch;
2 – windshield washer pump;
3 – clutch pedal;
4 – brake pedal;
5 – throttle pedal;
6 – radiator shutter control handle;
7 – hood catch handle;
8 – dome light switch;
9 – circuit breakers;
10 – choke button;
11 – temperature gauge;
12 – main light switch;
13 – temperature warning lamp;
14 – fuel gauge;
15 – speedometer;
16 – oil pressure warning lamp;
17 – ammeter;
18 – oil pressure gauge;
19 – turn signal indicator lamp;
20 – turn signal switch;
21 – ignition/starter switch;
22 – horn button;
23 – steering wheel;
24 – throttle hand lever;
25 – cowl ventilator handle;
26 – ventilator air intake control handle;
27 – gear shift lever;
28 – parking brake lever

placed in one of the following four positions: central position – all current consumers are switched off; first position clockwise – ignition is switched on; second position clockwise – ignition and the starter motor are switched on; first position counterclockwise – it is possible to actuate the horn, windshield wiper, and heater blower with the ignition circuit switched off.

Before starting the engine, it is necessary to check the radiator coolant level, the engine crankcase oil level, and the fuel level in the fuel tank.

To start a warm engine, place gear shift lever *27* in neutral and switch on ignition and the starter motor by turning the ignition key clockwise as far as it will go.

To start a cold engine (at ambient temperature of 0°C and upwards), it is recommended to do the following. Pump up gasoline (petrol) by using the fuel pump hand primer. Close the carburettor choke by pulling choke button *10* outward full distance. Place the gear shift lever in neutral. Disengage the clutch by depressing clutch pedal *3* all the way down to the cab floor, which will decrease drag on the engine and thus ease the operation of the starter motor, for in this case the transmission gears will not revolve in thickened oil during starting. Switch on ignition and the starter motor by turning the ignition key fully clockwise; limit the time the starter motor is energized to 5 s. Once the engine has started, switch off the starter motor by releasing the ignition key, open the choke by pushing its button inward one-half its full stroke, increase somewhat the engine speed by slightly depressing accelerator pedal *5*, and then engage the clutch by releasing its pedal. An engine in good repair usually starts after the first or second attempt. In the case of a false start, wait at least 30 s before attempting another start. If the engine has failed to start after the third attempt, check the ignition and fuel systems. If the trouble is with the starter motor or if the battery is discharged, the engine can be cranked up by hand. When cranking up, do not grasp the crank handle, but keep your fingers on its one side only, so that the hand may not get hurt if the engine kicks back (in the case of early ignition).

Before starting the engine in low-temperature conditions, shut off the oil cooler, fill the cooling system with hot water and the engine crankcase with hot oil or use the starting preheater (if available). Prior to turning on the ignition switch, close the radiator shutter by pulling handle *6* outward full distance and crank the engine three to five revolutions with the crank handle. Then perform all the rest operations as recommended for starting the cold engine.

AUTOMOBILE CONTROLS include clutch pedal *3*, brake pedal *4*, throttle (accelerator) pedal *5*, steering wheel *23*, gear shift lever *27*, and parking brake lever *28*.

Before starting to drive, warm up the engine at a moderate speed until the coolant temperature reaches 60°C. As the engine gets warmer, gradually open the choke and decrease the engine speed. A warm engine must run stably at a low speed with the choke fully open. Read the dashboard instruments to check on the operation of the engine.

TO MONITOR THE OPERATION of the engine and the automobile itself, use is made of the following instruments and indicators mounted on the instrument panel (dashboard) in front of the driver's seat: temperature gauge *11* and temperature warning lamp *13*, fuel gauge *14*, speedometer *15*, oil pressure warning lamp *16*, ammeter *17*, and oil pressure gauge *18*.

SIGNALLING is effected by means of horn button *22* and turn signal switch *20* mounted on the left-hand side of the steering column. Turning the directional signal switch handle downwards causes the left-hand side and tail lights to flash, thus giving indication of a left turn, and turning it upwards actuates the right-hand side and tail lights to indicate a right turn. Whenever either of the turn signal lights is switched on, turn signal indicator lamp *19* on the instrument panel starts flashing. The turn signal lights are switched off automatically when the automobile is straightened after turning.

On the left-hand side of the cab floor there is foot dimmer (beam selector) switch *1* which is used to switch over the head lights from high to

low beam and/or vice versa (with the main light switch in the third position). Main light switch *12* has three positions: *I* – all lights are off; *II* – side lights, licence plate light, tail marker lights, and instrument panel light are switched on; *III* – side lights, head lights (high or low, depending on the position of the foot dimmer switch), tail marker lights, instrument panel light, and licence plate light are switched on.

Mounted ON THE INSTRUMENT PANEL are windshield wiper and heater blower switches (not shown in the figure). The wiper and heater blower are switched on by turning their respective switches clockwise. The wiper switch has three positions: off, slow, and fast. That of the heater blower also has three positions: off, low air delivery, and high air delivery.

Mounted UNDER THE INSTRUMENT PANEL are radiator shutter control handle *6* and hood catch handle *7*. Pulling back on handle *6* will close the radiator shutter, and pulling back on handle *7* will release the hood catch. There are also two circuit breaker buttons *9*, cowl ventilator handle *25*, and ventilator air intake control handle *26*. With handle *25* in the extreme left-hand position, the cowl ventilator is fully open, and with the handle in the extreme right-hand position, it is fully closed. When handle *26* is in the extreme left-hand position, the air intake (outer ventilator) door is fully open, and when the handle is in the extreme right-hand position, it is fully closed.

To stop the engine, switch off ignition. Before stopping, let the engine run idle for one or two minutes at a slow speed, so that the engine components may cool down uniformly.

All automobiles and wheeled tractors equipped with battery starting systems have similar controls, and their engines are started and stopped in nearly one and the same manner.

2.2. Tractor Controls and the Starting of the Tractor Engine

In modern farm tractors powered by diesel engines (or simply diesels) that are started by means of an auxiliary starting engine, all

5

Controls of the ДТ-75М Model tractor

1 – gas tank shut-off cock control handle;
2 – tachometer/speedometer;
3 – heater blower and ventilator switch;
4 – fuel pressure gauge;
5 – carburettor choke control handle;
6 – ammeter;
7 – head light switch;
8 – decompressor control lever;
9 – left-hand steering control lever;
10 – right-hand steering control lever;
11 – magneto grounding switch;
12 – engine coolant temperature gauge;
13 – oil pressure warning lamp;
14 – torque multiplier oil pressure gauge;
15 – starter motor switch;
16 – engine oil pressure gauge;
17 – battery switch indicator lamp;
18 – horn button;
19 – torque multiplier control lever;
20 – fuel pump lever (governor override);
21 – master clutch pedal;
22 – driver's seat;
23 – PTO shifter lever;
24 – right-hand brake pedal lock ratchet;
25 – right-hand brake pedal;
26 – left-hand brake pedal;
27 – starting gear clutch and drive pinion control lever;
28 – gear shift lever;
29, 30, and 31 – hydraulic control levers for the right-hand remote control, main, and left-hand remote control hydraulic cylinders of mounted implements

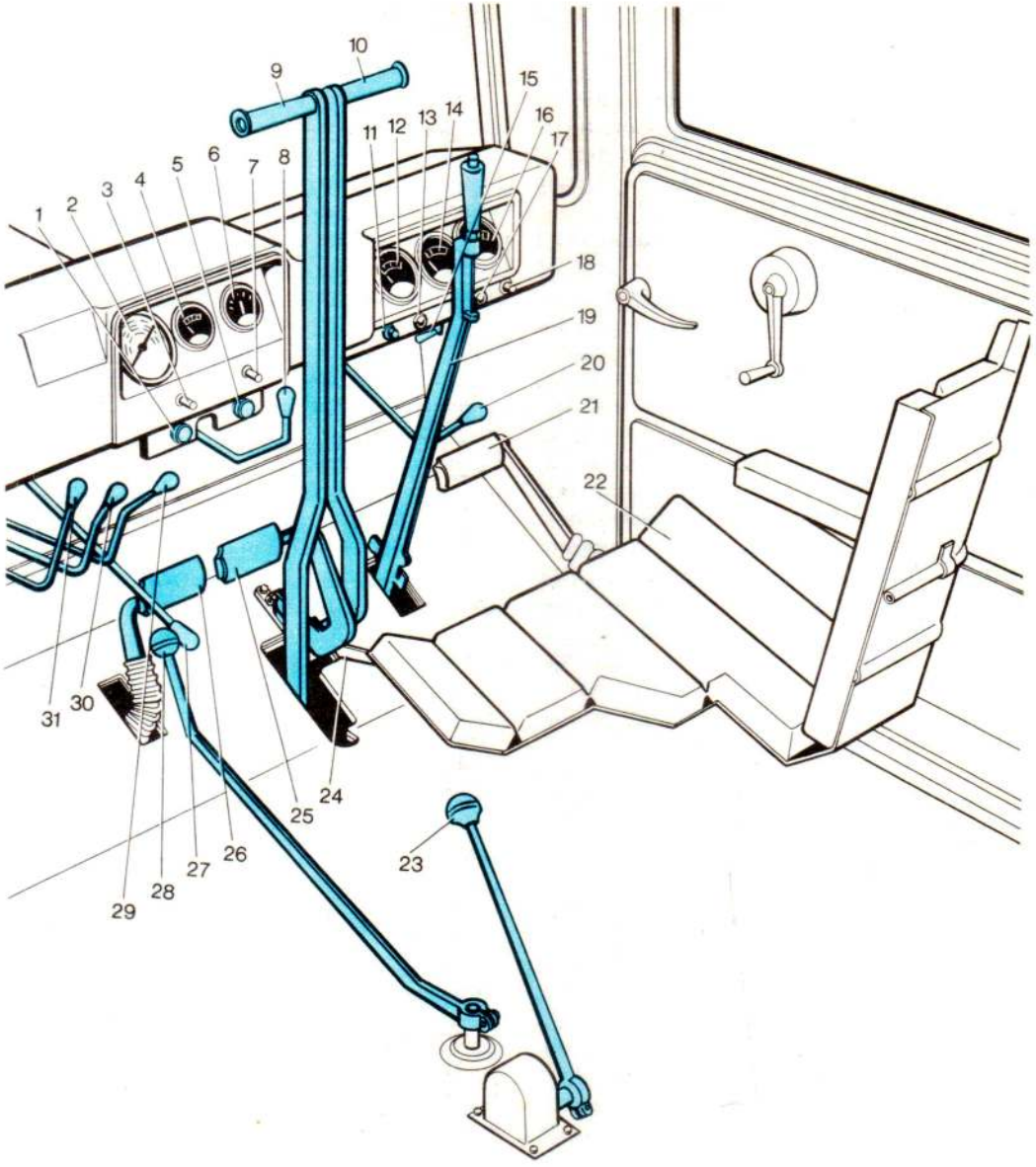
controls are arranged in the driver's cab (Fig. 5), thanks to the remote control of the starting system.

TO PREPARE THE STARTING ENGINE FOR OPERATION and to control it, use is made of the following controls: gas (petroleum) tank shut-off cock control handle *1*, carburettor choke control handle *5*, magneto grounding switch *11*, starter switch *15*, and starting gear clutch and drive pinion control lever *27*.

TO PREPARE THE MAIN TRACTOR ENGINE (i.e., the diesel engine) FOR OPERATION, the following controls are used: decompressor (compression release) control lever *8*, fuel pump lever *20*, battery ground switch (not shown in Fig. 5), fuel cock, and hand priming pump (located outside the cab).

THE TRACTOR IS CONTROLLED by means of the following levers and pedals located in the driver's cab.

Steering control levers *9* and *10* (in crawler tractors). To turn the tractor through a large-radius arc, smoothly pull back on the corresponding lever.



Torque multiplier control lever *19*. Pulling back on this lever engages the multiplier. The lever can be locked in the engaged position by means of a dog.

Fuel pump lever *20*. Moving the lever downward increases the fuel feed. The fuel feed is shut off when the lever is moved all the way upwards.

Master clutch pedal *21*. The clutch is disengaged by depressing the pedal as far as it will go.

Power takeoff shifter lever *23*. This control lever engages or disengages the power takeoff

shaft. The shaft is engaged when the lever is moved backwards.

Right- and left-hand brake pedals *25* and *26*. These pedals can be used together with the steering control levers for making short turns. To make such a turn, only that brake pedal is depressed whose corresponding steering control lever is pulled back.

Gear shift lever *28* is used to select the desired transmission gear. Gears can only be shifted when the master clutch is disengaged.

Hydraulic control levers *30*, *29*, and *31* for the main and remote control hydraulic cylinders of mounted implements, which are located at the rear and on the right- and left-hand sides of the tractor, respectively. All three levers are identical and have four positions as follows: first locked position – neutral (the corresponding implement is locked in position, i.e., cannot lift or lower), extreme upward position (not locked) – up pressure (the implement is lifted), second locked position downwards – down pressure (the implement is lowered), and third locked position downwards – floating (the implement floats up and down, following the contour of the ground).

INSTRUMENTS, INDICATORS, AND SIGNALLING DEVICES include tachometer/speedometer *2*, fuel pressure gauge *4*, ammeter *6*, temperature gauge *12*, oil pressure warning lamp *13*, torque multiplier oil pressure gauge *14*, engine oil pressure gauge *16*, battery switch indicator lamp *17*, and horn button *18*.

PREPARING THE ENGINE FOR STARTING. Before starting a cold engine, perform all the daily attention and inspection procedures; bleed air from the fuel feed system (if the engine has been out of service for a long time) and fill the system with fuel, using the hand priming pump; place gear shift lever *28* and hydraulic control levers *29*, *30*, and *31* in neutral and disengage the power takeoff shaft, using PTO shifter lever *23*; close the radiator shutter and remove the right-hand side panel of the hood.

STARTING THE ENGINE. To ease the cranking of the diesel engine, engage the decompressor (compression release) by placing lever *8* in the extreme downward position. If the engine has not been started a long time, crank it two or three revolutions with the crank handle.

Open the shut-off cocks of the main fuel tank and the starting engine fuel tank. The latter is opened by turning control handle *1* counterclockwise. Shut off the fuel feed of the diesel (main) engine by placing fuel pump lever *20* in the extreme upward position. Engage the drive pinion with the diesel flywheel ring gear by moving control lever *27* all the way upwards and then place the lever back in the downward position to disengage the starting gear clutch.

Close the carburettor choke of the starting engine by pulling back on control handle *5*. Place the battery in circuit by depressing the larger button of the battery ground switch until it locks in the "ON" position.

Then switch on the starter motor by turning starter switch *15* clockwise as far as it will go.

After the starting engine has started, fully open the carburettor choke by depressing control handle *5* all the way inwards and let the engine run idle for no more than two minutes. A prolonged idling of the starting engine causes its overheating.

Once the starting engine is warm enough, smoothly engage the starting gear clutch and crank the diesel, with the decompressor being engaged, during one or two minutes until oil pressure develops in the lubricating system of the engine, and then disengage the decompressor. If at that time the starting engine begins slowing down, engage the decompressor again, crank the diesel a little longer, and disengage the decompressor once more. With the starting engine running smoothly, turn on the fuel feed of the diesel to the full. After the diesel has started operating stably, disengage the starting gear clutch, kill the starting engine by depressing the button of magneto grounding switch *11*, and place the fuel pump lever in a middle position. Operating the starting engine for more than 15 min at a time is not allowed.

If the starter motor or the storage battery is faulty, the starting engine can be started by hand. To do this, remove the engine flywheel guard together with the starter motor, place the

knot at the end of the starting rope in one of the recesses in the flywheel, coil one and a half or two turns of the rope around the groove in the flywheel in the direction indicated on the latter by an arrow, and start the engine by tugging sharply at the starting rope handle. Hold the rope by the handle only. It is prohibited to coil the rope around the hand, for the engine may kick back during starting and crush the hand between the flywheel and the rope. If the engine fails to start after three or four attempts, check the ignition and fuel feed systems, rectify faults, and repeat the starting procedures. After the diesel engine has started, close the fuel cock of the starting engine, install the hood side panel in place, and stow the tools used.

After starting, warm up the diesel during two or three minutes, gradually increasing its speed from moderate to maximum. At that time, listen closely to the engine and read the instruments to check its operation. The engine must run smoothly, without missing and knocking, and its exhaust must be smokeless. It may be loaded only after the coolant temperature has reached 50°C. After the temperature has climbed to 75°C, the radiator shutter must be placed in the fully open position.

In a warm engine, the oil pressure in the lubricating system must be within 0.3 to 0.5 MPa. If the oil pressure gauge reads no pressure, the engine must be immediately stopped and the trouble removed.

During warm weather the diesel engine can be started without engaging the decompressor. In this case, crank the engine with the fuel feed shut off until oil pressure is developed in the lubricating system and then turn on the fuel feed.

To ease the starting of the engine *under low-temperature conditions*, use the starting preheater (if available) or fill the cooling system with hot water and the engine crankcase with hot oil. In bitter frosts, first open the radiator drain cock and pass hot water at 60 to 70°C through the cooling system and then close the cock and fill the system with hot water at 90 to 95°C. To facilitate the starting of the engine, pour 2 to 3 cm^3 of a gasoline-oil mixture into the starting engine cylinder through the cock on the cylinder head and pull back the governor booster control button on the fuel pump.

To stop the diesel engine, shut off the fuel feed. Prior to stopping, let the engine run idle at a moderate and then slow speed for three to five minutes so as to allow the coolant and oil temperature to drop down uniformly. Do not stop the engine by closing the fuel cock, for this may cause suction of air into the fuel feed system, which will hamper subsequent starting of the engine. After stopping the diesel, disconnect the battery by depressing the smaller, side button of the battery ground switch. This should cause battery switch indicator lamp *17* to go out.

2.3. Safety Rules

Modern tractors and automobiles are designed for safe operation, but to prevent accidents in operating them, one must know and observe without fail the following basic safety rules.

Only specially trained persons not under 18 years of age and carrying appropriate certificates of competence may be allowed to drive a tractor or an automobile. Unauthorized persons must not be permitted to start the engine of a tractor or an automobile and operate the machine. It is impermissible to operate a tractor or an automobile with faulty brakes, steering mechanism or running gear. The clothing worn by the driver should be fairly tight fitting and belted. Loose jackets, shirts or sleeves should not be permitted because of the danger of getting into moving parts. A tractor or an automobile should be provided with a first-aid kit for use in case of accident.

Before starting the engine, make sure that the gear shift lever is in neutral.

Before starting away from rest, take a look around, switch on the corresponding turn signal, and then smoothly start driving. When stopping a wheeled tractor or an automobile, select a suitable parking spot in advance, reduce the running speed so as to reach the spot by coasting, and apply the brakes only to fully stop the vehicle. When stopping on a roadway

in dark hours, switch on the marker (parking) lights; pull off the roadway whenever possible. In emergency braking, consider the condition of the road and if the pavement is slippery, brake with the engine without disengaging the clutch in order to avoid skidding until the speed has dropped sufficiently low and only then apply the brakes and disengage the clutch.

In each particular case, the driving speed must conform to the current situation on the road, driver's experience, traffic density, and road conditions. As the road conditions worsen, the driving speed must be reduced.

If the tractor or automobile is equipped with a pneumatic (compressed air) brake system, do not shut the engine dead off when driving downhill, for the store of compressed air in the brake reservoirs is good for a few braking actions only.

While driving a tractor or an automobile, the driver experiences static load stresses that depend on the position of his trunk and limbs and eventually cause physical fatigue. The driver's posture in the cab should be natural, free from tension. On the other hand, too relaxed a seat and careless holding of the steering wheel should not be allowed, for in this case the driver's attention becomes dull so that he cannot react quickly enough to perform the necessary manoeuvre should the need arise.

Railway tracks should be crossed in low gear and where permitted only. It is prohibited to drive over bridges and corduroy roads without checking their load capacity.

Special care should be exercised when operating on hillsides, because the tractor or automobile may overturn if it strikes some irregularity.

When driving from one field to another, avoid running over bushes and tall grass. Switch on the headlights when operating at night or in dense fog. Do not operate on steep hillsides or mountainous plots in dark hours. It is prohibited to rest in heaps of hay or straw, as well as in a furrow or grass where tractor-operated implements are at work.

When stopping a tractor or an automobile for any prolonged period of time, shut off the engine, make sure that the machine cannot coast, and lower the mounted agricultural implements.

Tractor and automobile drivers must know and strictly adhere to the traffic regulations.

SPECIAL SAFETY MEASURES TO BE TAKEN WHEN OPERATING TRACTORS. Before starting work, inspect the mounted implement operated by the tractor. The hitch must be in good working order. The power takeoff linkage between the tractor and the PTO-driven machine or implement must be guarded by a metal shield. Whenever the power take-off shaft is not used, its free end must be protected by a guard.

To avoid premature ignition, do not start the starting engine when it is overheated. The starting rope must be strong and dry and must have at one of its ends a wooden handle 20 mm in diameter and 50 to 70 mm long. The rope should be passed between the middle and the ring finger. It is prohibited to crank the starting engine flywheel by hand without disconnecting the magneto wire from the spark plug.

Do not make any adjustments on the tractor or on any machine carried or towed by the tractor while the engine is running. It is prohibited to be under the tractor or the machine carried or towed by it when the engine is running. Before climbing into the tractor cab, clean your footwear from dirt so that your feet may not slip on the cab floor and control pedals.

Do not throw into gear if there are people in the way or between the tractor and the machine towed by it. Before starting away from rest, warn the operators seating on the drawn machine or implement. When attaching an implement, approach it slowly in reverse and be prepared to stop the tractor at any moment.

Never enter the space between the draft links when attaching an implement to the tractor hitch; place the hydraulic control lever into the floating position to complete the attachment. Before lifting or lowering a mounted implement and also before rounding a turn, make sure that there is no danger of hitting somebody. When stopping for a long period of time, do not leave the mounted implement in the lifted position.

In belt work, all pulleys and belts must be

guarded by protective shields and screens. Never force a belt on or off a revolving pulley. Do not inspect a PTO-driven machine without disengaging the power takeoff shaft. To avoid the drawn machine or trailer running into the tractor, use only rigid towing attachments.

Never ride or permit others to ride on the mounted implement or drawbar of the tractor. Do not dismount from the tractor or mount it, or else move from the tractor onto the drawn machine, while the tractor is in motion.

During transport operations observe the following additional rules. Set the tractor wheel track at no less than 1600 mm. Check and if necessary adjust the brakes so as to make them operate simultaneously and interlock the brake pedals. Use only trailers equipped with brakes. Never carry people in a trailer. Always keep the tractor in gear when going with a trailer downhill.

FIRE PREVENTION RULES. The following are the basic rules to be observed in order to prevent the outbreak of fire. Do not smoke or start a wood fire near refuelling points and never use naked flame when checking for the presence of fuel in drums and tanks. Use cotton waste to remove spilled oil and/or fuel from the surface of the tractor or automobile and keep oil-soaked waste in lidded metal boxes.

Periodically check the condition of electrical equipment and wiring, for a spark may be the cause of fire. If wiring should catch fire as a result of a short circuit, immediately switch off loads (using equipment) or disconnect the wiring and then fight the fire as usual.

It is prohibited to come close to a wood fire while wearing oil-soaked clothing, use naked flame to preheat the engine in cold weather, unscrew the plugs of gasoline drums by striking blows against the plugs with metal objects.

During harvesting and threshing, equip the exhaust pipe of your tractor with a spark arrester and check its condition every three days; remove carbon deposit from the exhaust pipe and muffler. Every tractor and automobile must be provided with a fire extinguisher.

Do not refuel your tractor or automobile during a thunderstorm. Do not store fuel and lubricants near heaps of hay, straw, or unthreshed grain, or else directly in grain fields.

If fire breaks out, immediately cover the flames up with clothing free from oil stains, or a piece of canvas or felt, extinguish them with water, or blanket them with earth or sand. If petroleum products catch fire, put it out with a fire extinguisher, blanket it with earth or sand, or cover the flames with a piece of canvas or felt, but never use water.

Review Questions

1. Show on Fig. 4 the controls used to start the automobile engine.
2. How is a warm automobile engine started?
3. Show on Fig. 4 the automobile controls.
4. How is the automobile engine stopped?
5. Show on Fig. 5 the controls used to prepare the starting engine for operation.
6. Show on Fig. 5 the levers and pedals used to control a crawler tractor.
7. What is to be done to prepare the main tractor engine for starting?
8. How is the starting engine started by hand?
9. How is the tractor engine started in cold weather?
10. How is the diesel engine stopped?
11. Quote the safety rules to be adhered to when operating the tractor.
12. Quote the basic fire prevention rules.

Part II
THE ENGINE

Chapter 3

Fundamentals of Engine Operation and Construction

3.1. Basic Notions and Definitions

CLASSIFICATION OF ENGINES. Modern farm tractors and automobiles are powered by piston-type internal combustion engines. An internal combustion engine is one in which the thermal energy supplied by a burning fuel is directly transformed into mechanical energy by the controlled combustion of the fuel in an enclosed cylinder behind a piston. Such engines are classified according to the following basic features:

(a) by the method of mixing fuel and air: engines with external mixing – carburettor engines and gas engines; engines with internal mixing – diesel engines;

(b) by the method of ignition of air-fuel mixture: spark ignition engines – carburettor engines and gas engines; compression ignition (self-ignition) engines – diesel engines;

(c) by the number of piston strokes in one complete cycle of operations: four-stroke engines and two-stroke engines;

(d) by the kind of fuel used: gasoline (petrol) engines, gas engines, and diesel engines;

(e) by the cooling method: liquid-cooled engines and air-cooled engines;

(f) by the number of cylinders: single cylinder engines and multicylinder engines (double-cylinder, four-cylinder, six-cylinder, eight-cylinder, and twelve-cylinder engines);

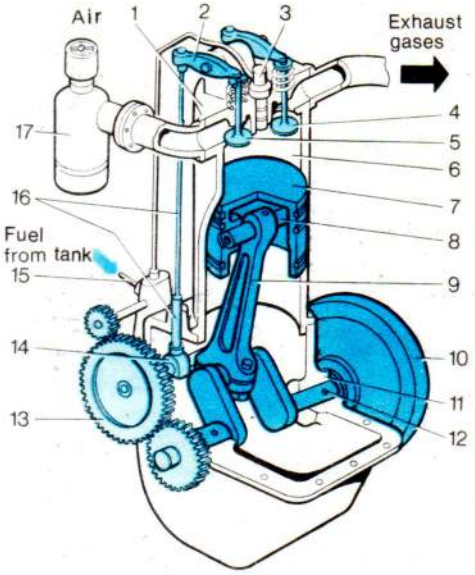
(g) by the cylinder arrangement: single-row engines and double-row engines including V-type ones in which the two rows of cylinders are arranged at an angle to each other.

BASIC NOTIONS. It takes oxygen to burn the fuel, therefore the latter is mixed with air. A mixture of atomized fuel and air in certain proportions by weight is called air-fuel mixture. The air-fuel mixture entering a cylinder of a running engine intermingles with unscavenged exhaust gases and thus forms what is known as the combustible charge.

Engines using a special device – carburettor – to mix fuel with air are referred to as carburettor engines. In such engines, the air-fuel mixture is ignited by a spark. In diesel engines, the air-fuel mixture forms inside the cylinder and is self-ignited by the heat of compressed air. Carburettor engines are used mainly on light and medium trucks and cars and also on tractors where they serve to start the main engines. The main engines powering modern tractors and heavy trucks are of the diesel type.

Referring to the simplified diagram of Fig. 6, consider the operation of the diesel engine.

Piston *7* is placed inside cylinder *6*. The piston is attached to crankshaft *12* through the intermediary of connecting rod *9*. If the piston is moved up and down in the cylinder, this up-and-down, or reciprocating, motion of the piston is changed into the rotary motion of the crankshaft by the connecting rod and the crank of the shaft. Flywheel *10* fastened to the rear end of the crankshaft serves to make the shaft revolve uniformly when the engine is running. The cylinder is tightly closed at the top by cylinder head *1* housing two valves. Intake



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Schematic diagram of a single-cylinder diesel engine

1 – cylinder head;
2 – rocker arm;
3 – fuel injector;
4 – exhaust valve;
5 – intake valve;
6 – cylinder;
7 – piston;
8 – piston pin;
9 – connecting rod;
10 – flywheel;
11 – crankcase;
12 – crankshaft;
13 – camshaft timing gear;
14 – camshaft;
15 – fuel injection pump;
16 – valve lifter (tappet) and push-rod;
17 – air cleaner

valve *5* admits air into the cylinder and exhaust valve *4* lets the burnt gases out. The valves are held closed by valve springs and are made to open by means of rocker arms *2* which are actuated by camshaft *14* through intermediate components (valve lifters and push-rods). The camshaft and the fuel injection pump shaft are driven by the crankshaft through gears *13*. The fuel supplied by the fuel injection pump is injected into the cylinder through fuel injector *3*.

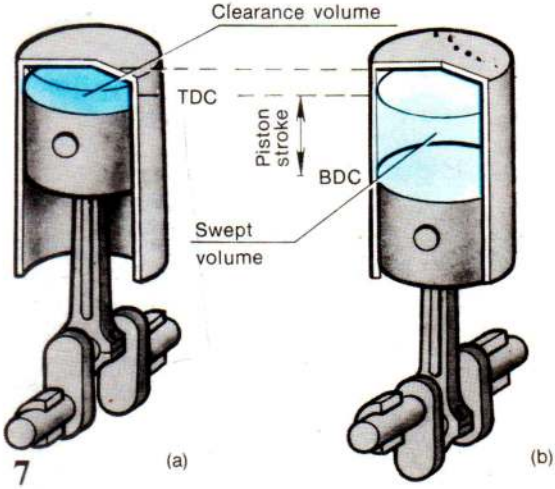
The carburettor engine differs from the single-cylinder diesel engine shown in Fig. 6 in that the intake port closed by valve *5* serves to admit air-fuel mixture into the cylinder and a spark plug takes the place of the fuel injector in the cylinder head.

BASIC DEFINITIONS. The piston, while reciprocating inside the cylinder, can occupy two extreme positions (Fig. 7). The uppermost position of the piston is termed the *top dead center* (TDC), while the lowermost position is referred to as the *bottom dead center* (BDC). The distance travelled by the piston from one dead center to the other is called the *piston stroke*. During one piston stroke the crankshaft rotates half a turn.

The space between the cylinder head and the piston at the top dead center is known as the *combustion*, or *compression*, *chamber* and the volume of this space is referred to as the *clearance volume*. The volume displaced by the piston as it moves from the bottom dead center to the top dead center is termed the *displacement*, also known as the *swept*, or *stroke*, *volume* (V):

$$V = \frac{\pi d^2}{4} S$$

where d is the piston diameter, *dm*, and S is the piston stroke, *dm*.



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Piston positions at dead centers

(a) piston at TDC;
(b) piston at BDC

The displacement of an engine cylinder is measured in litres. The displacement of all the cylinders of an engine is termed the *engine displacement*, or *capacity*. It is measured in cubic centimeters in small-displacement (up to 1 l) engines and in liters in large-displacement ones.

The total volume enclosed above the piston at the bottom dead center, i.e., the clearance volume plus swept volume, is called the air volume. The number showing how many times the clearance volume is the air volume, i.e., the ratio between the air volume and clearance volume, is known as the *compression ratio*. In modern carburettor engines, the compression ratio ranges from 6 (6 : 1) to 9 (9 : 1), reaching 15 (15 : 1) to 20 (20 : 1) in diesel engines.

A number of events occur in the cylinder of a running engine. First the cylinder is filled with an air-fuel mixture or air. Then the mixture or air is compressed. After igniting, the mixture of fuel and air burns and the gases formed as a result expand, push on the piston, and make it move, thus performing mechanical work. Then the burnt gases are purged from the cylinder. The above events are continuously repeated in a definite sequence all the time the engine is running and constitute the working cycle, or the cycle of operations, of the engine.

3.2. Engine Cycles

An event (a part of the engine cycle) that occurs in the engine cylinder during one piston travel is called a stroke. The engine which completes its working cycle in four strokes of the piston is known as the four-stroke-cycle, or simply four-stroke or four-cycle, engine.

WORKING CYCLE OF THE FOUR-STROKE DIESEL ENGINE. Let us consider the sequence of events occurring in one of the cylinders of the running engine.

1st STROKE – INTAKE (Fig. 8*a*). The piston is moved by the crankshaft and connecting rod downwards and, acting like a pump piston, it produces a vacuum in the cylinder. Fresh air is taken into the cylinder through the open intake valve, as a result of the pressure differential between the cylinder and atmospheric air. The exhaust valve is closed. At the end of the intake stroke, the intake valve closes. The pressure in the cylinder at the end of the intake stroke comes to an average of 0.08 to 0.095 MPa and the air temperature, 30 to 50°C.

2nd STROKE – COMPRESSION (Fig. 8*b*). The crankshaft continues to rotate, so the piston, after passing BDC at the end of the intake stroke, starts moving upwards. Since both the intake and the exhaust valves are closed, the piston compresses the air in the cylinder. As the air is compressed, its temperature goes up. The compression ratio of the diesel engine being fairly high, the pressure in the cylinder rises up to 4 MPa and the air gets heated up to 600°C. As the piston nears TDC at the end of the compression stroke, a charge of finely atomized diesel fuel is injected into the cylinder through the fuel injector.

3rd STROKE – POWER, or expansion (Fig. 8*c*). On coming into contact with the hot compressed air in the cylinder, fine fuel particles are self-ignited. The injection and burning of fuel go on for some time after the piston has passed TDC at the beginning of the power stroke. Because of a delay in the self-ignition of fuel, it burns mainly during this piston stroke. During the power stroke, both valves are closed. The temperature of combustion gases reaches 2000°C and the pressure in the cylinder increases up to 8 MPa. The high pressure of expanding gases pushes the piston downward. The piston transmits this push through the connecting rod to the crankshaft, making the latter perform mechanical work.

4th STROKE – EXHAUST (Fig. 8*d*). As the piston reaches BDC on the power stroke, the exhaust valve opens to release the burnt gases under an excessive pressure. The piston then moves upwards again and pushes all of the exhaust gas from the cylinder. Finally, as the piston reaches TDC on the exhaust stroke, the exhaust valve closes and the intake valve opens. The piston then moves downwards once more on another intake stroke, and the cycle of events in the cylinder is then repeated.

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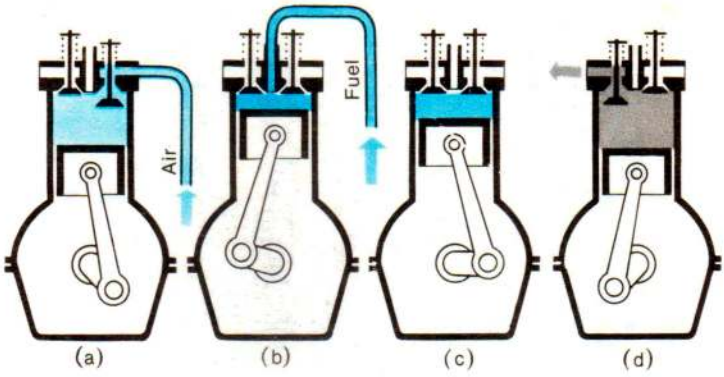
Illustrating the operation of a single-cylinder four-stroke engine

(a) the first (intake) stroke; (b) the second (compression) stroke; (c) the third (power) stroke; (d) the fourth (exhaust) stroke



Before the engine has fired, the crankshaft is rotated by means of an external power source, e. g., an electrical starter motor or a starting engine, since energy is necessarily required to perform the initial intake and compression strokes.

WORKING CYCLE OF THE FOUR-STROKE CARBURETTOR ENGINE. As distinct from the diesel engine, in the carburettor engine, fuel and air enter the cylinder in the form of an air-fuel mixture prepared by the carburettor.

Each of the strokes in the working cycle of the four-stroke carburettor engine, as in the diesel engine, is characterized by the position of the valves and the direction of the piston travel. The cycle of operations of the four-stroke carburettor engine occurs as follows.

INTAKE – the piston moves downwards. The intake valve is open. As a result of a vacuum produced by the downward movement of the piston, the air-fuel mixture prepared by the carburettor enters the cylinder through the open intake port and, intermingling with the unscavenged exhaust gases, forms the combustible charge.

COMPRESSION – the piston moves upwards. Both the intake and the exhaust valves are closed. The volume above the piston diminishes and the combustible charge is compressed, which facilitates the evaporation of gasoline and mixing of gasoline vapor with air. By the end of the compression stroke, the pressure in the cylinder reaches 1 to 1.2 MPa and the temperature, 350 to 400°C.

POWER – burning of fuel and expansion of combustion gases. Both valves are closed. At the end of the compression stroke, the combustible charge is ignited by a spark. The piston moves down from TDC to BDC under the pressure of expanding combustion gases. The pressure of the gases reaches 2.5 to 4 MPa and their temperature, 2000°C.

EXHAUST – the piston moves upwards. The exhaust valve is open. The spent exhaust gases leave the cylinder through the exhaust port.

Diesel engines are more economical than their carburettor counterparts. As a result of their higher compression ratio, the diesel engines burn 25% less fuel (per unit work done).

Diesel engines operate on heavy fuels that present less fire hazard in handling.

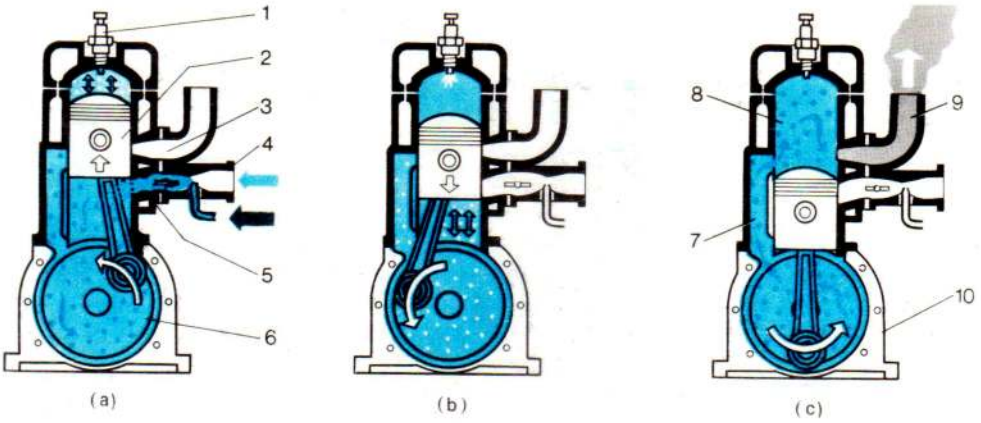
The diesels, however, feature some disadvantages:

they are more bulky, for the high pressure of combustion gases in the cylinder requires stronger engine components;

they are more difficult to start, especially in cold weather.

WORKING CYCLE OF THE TWO-STROKE CARBURETTOR ENGINE (Fig. 9). The two-stroke engine has no valves. The intake of the air-fuel mixture and the exhaust of the burnt gases are effected through ports cut in the cylinder wall, which are timely opened and closed by the moving piston.

As piston *2* (Fig. 9*a*) moves upwards, it closes exhaust ports *3* in the cylinder wall, as a result of which final compression of the combustible



9

Illustrating the operation of a two-stroke engine

(a) the first (intake cum compression) stroke;
(b) the end of the first stroke and the beginning of the second (power cum exhaust) stroke;
(c) the end of the second stroke;
1 – spark plug;
2 – piston;
3 – exhaust port;
4 – carburettor;
5 – intake port;
6 – crank chamber;
7 – scavenging (transfer) passage (port);
8 – cylinder;
9 – exhaust pipe;
10 – crankcase

charge transferred earlier in the stroke from sealed crank chamber *6* to the cylinder takes place above the advancing piston. At the same time, a fresh charge of fuel and air is taken from carburettor *4* into crank chamber *6* through intake ports *5*, as a result of the depression produced below the piston as it retards towards the end of its stroke.

As the piston nears TDC, a spark jumps across the points of spark plug *1* (Fig. 9*b*) and the combustible charge in the cylinder is ignited. This marks the end of the first (intake) and compression stroke.

Under the pressure of the expanding combustion gases the piston moves downwards on its power stroke which continues until the exhaust ports are opened and the evacuation of the exhaust gases from the cylinder commences. As the piston moves downwards, the previously induced charge trapped in the crank chamber beneath the advancing piston is partially compressed. At the end of the second (power and exhaust) stroke, the piston opens scavenging (transfer) passage (port) *7* and the partially compressed charge of air-fuel mixture previously trapped in the crank chamber enters the cylinder, expelling the exhaust gases out of it (Fig. 9*c*). The cylinder is simultaneously scavenged and filled with a fresh air-fuel mixture, the latter being partially lost together with the exhaust gases leaving the cylinder. Thus, the working cycle of the engine is completed in two strokes of the piston.

Engines with the above-described cycle of operations are referred to as scavenging engines. These engines are simpler, both in design and operation, than four-stroke engines. They run more smoothly, because the power stroke in them occurs at each revolution of the crankshaft. Two-stroke engines, however, are less economical than four-stroke ones, up to 30% of air-fuel mixture being lost in scavenging. For this reason, such engines in tractors are used only under short-term service conditions for starting the main diesel engine.

3.3. Operation of Multicylinder Engines

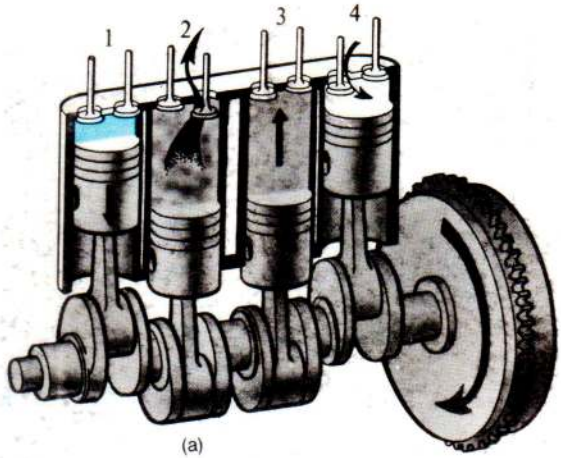
The cycle of operations of four-stroke engines is completed in two turns of the crankshaft. With such an operating cycle, the crankshaft receives energy from the piston only during one half its turn when the piston moves on the power stroke. During the remaining three half turns, the crankshaft continues to revolve by inertia and, aided by the flywheel, it moves the piston on all its supplementary strokes – exhaust, intake, and compression. Therefore, the crankshaft of a single-cylinder engine operating on the four-stroke principle revolves nonuniformly: it accelerates on the power stroke and decelerates on the supplementary strokes of the piston. Furthermore, the single-cylinder engine usually produces little power and features excessive vibration. For this reason, modern tractors and automobiles are powered by multiple-cylinder engines.

For a multicylinder engine to run uniformly, the power strokes of its pistons must be spaced rotationally at one and the same crank angle (i. e., they must occur at regular intervals, called the firing intervals). To find this angle, the duration of the engine cycle, expressed in degrees of crankshaft rotation, is divided by the number of the engine cylinders. For example, in a four-cylinder four-stroke engine, the power stroke occurs every 180° (720° : 4), i. e., every half turn of the crankshaft. The other strokes in this engine occur also every 180°. Therefore, the crankshaft throws (or crankthrows) of four-cylinder four-stroke engines are spaced at 180°, i. e., they lie in a single plane. The crankthrows of the first and fourth cylinders are arranged on one side of the crankshaft, and those of the second and third cylinders, on the opposite side. Such a shape of the crankshaft provides for even firing intervals and a good engine balance, since all the pistons simultaneously reach their extreme positions (two pistons reach their TDC at the same time as the other two reach BDC).

The order in which like piston strokes occur in the engine cylinders is known as the firing order. The firing order of the four-cylinder tractor engines produced in this country is 1-3-4-2. This means that after the piston in the first cylinder has completed its power stroke, the next power stroke occurs in the third cylinder, then in the fourth cylinder, and finally, in the second cylinder (Fig. 10).

When selecting a firing order for a particular engine, the designers try to distribute the load on the crankshaft as uniformly as possible.

Multicylinder engines used on automobiles and tractors may have an in-line or a two-bank

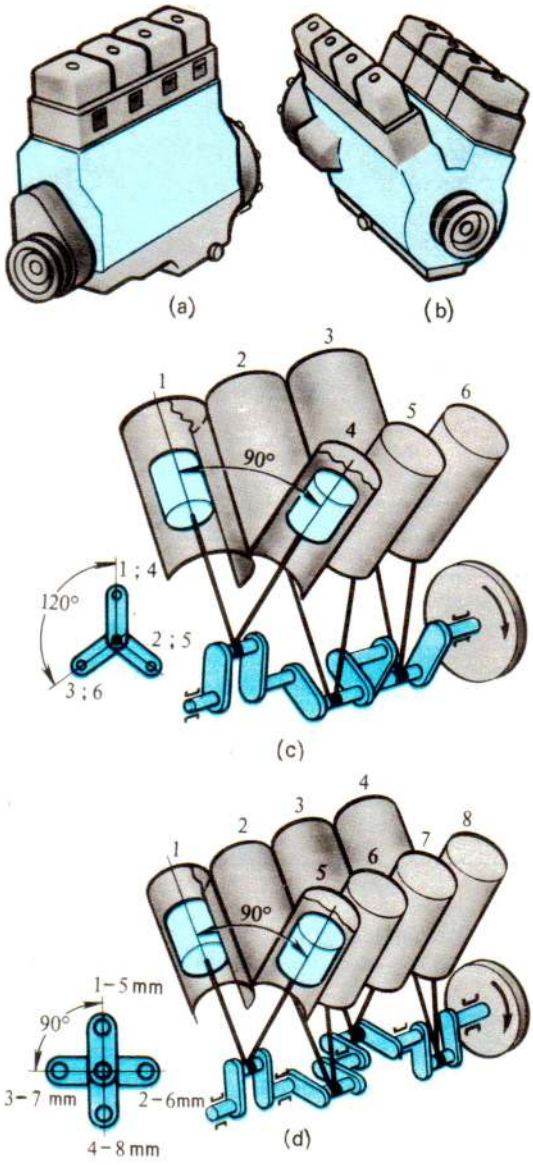


(a)

Crankshaft half turns	Cylinders			
	1	2	3	4
1st stroke 0 to 180°	power	exhaust	compression	intake
2nd stroke 180 to 360°	exhaust	intake	power	compression
3rd stroke 360 to 540°	intake	compression	exhaust	power
4th stroke 540 to 720°	compression	power	intake	exhaust

10 (b)

(a) Schematic diagram and (b) firing-order diagram of a four-cylinder four-stroke engine



11

Multicylinder engines

(a) in-line cylinder arrangement;
(b) V-type cylinder arrangement;
(c) and (d) crankthrow arrangements in V-6 and V-8 type engines, respectively; 1 through 8 – serial numbers of cylinders

(V-type) cylinder arrangement. In an in-line cylinder engine (Fig. 11*a*), all the cylinders are arranged vertically in a straight line, while in a two-bank engine, the cylinders are arranged in two banks set at an angle to each other (Fig. 11*b*). V-type engines are more compact and less heavy than their in-line cylinder counterparts.

In a six-cylinder four-stroke engine, like piston strokes occur at 120-degree intervals. Therefore, its crankthrows are spaced in pairs in three planes with an angle of 120° between them (Fig. 11*c*). In an eight-cylinder four-stroke engine, like piston strokes occur every 90°, and so the crankthrows are arranged crosswise with an angle of 90° between them (Fig. 11*d*). With an eight-cylinder four-stroke engine, eight power strokes occur for every two revolutions of the crankshaft, which makes for very smooth running of the engine. Modern six- and eight-cylinder automotive engines use V-type cylinder arrangements. The firing order of eight-cylinder four-stroke engines is 1-5-4-2-6-3-7-8 and that of six-cylinder ones, 1-4-2-5-3-6.

Knowing the firing order of an engine, one can correctly connect the ignition wires to the spark plugs, or the fuel pipes to the fuel injectors, and adjust the valves.

3.4. General Engine Design

For an engine to operate normally, its cylinders must be supplied with a homogeneous mixture of fuel and air in definite proportions (in carburettor engines) or with metered-out charges of fuel injected under a high pressure at strictly defined moments (in diesel engines). To reduce the amount of work done in overcoming friction, to withdraw heat, and to prevent scuffing and premature wear, all the rubbing parts of the engine are lubricated with oil. The engine must be cooled in order to create normal temperature conditions in the cylinders. The high compression ratio of diesel engines prevents the possibility of their being started by hand, and so these engines are provided with a starting device. All engines used to power

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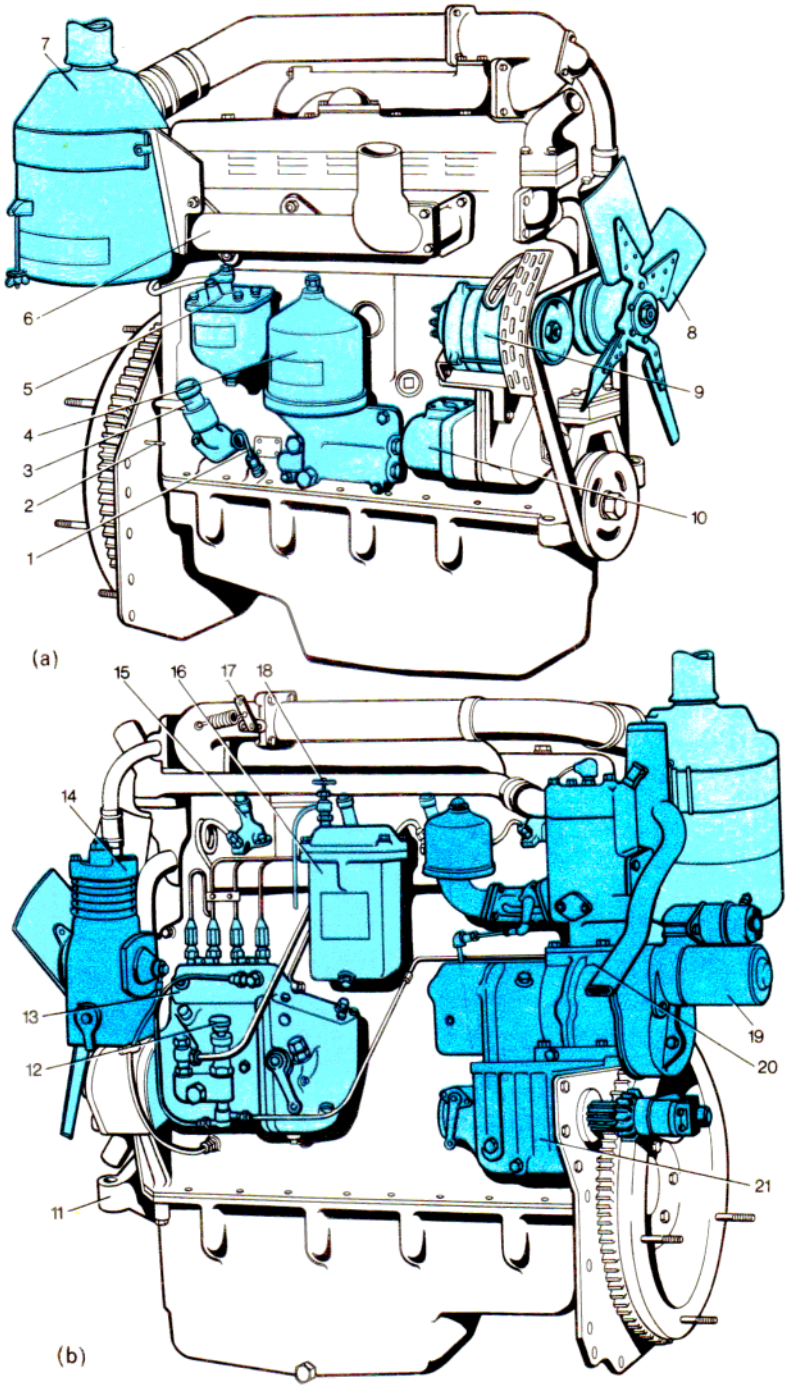
The Д-240 Model tractor diesel engine

(a) right-hand side view;
(b) left-hand side view;
1 – oil level dipstick;
2 – timing pin;
3 – oil filler;
4 – oil filter;
5 – primary fuel filter;
6 – exhaust manifold;
7 – air cleaner;
8 – fan;
9 – generator;
10 – hydraulic servo steering pump;
11 – engine front support;
12 – hand priming pump;
13 – fuel injection pump;
14 – compressor;
15 – fuel injector;
16 – secondary fuel filter;
17 – emergency engine shut-down air throttle lever;
18 – fuel system air vent valve;
19 – starter motor;
20 – starting engine;
21 – starting reduction gear



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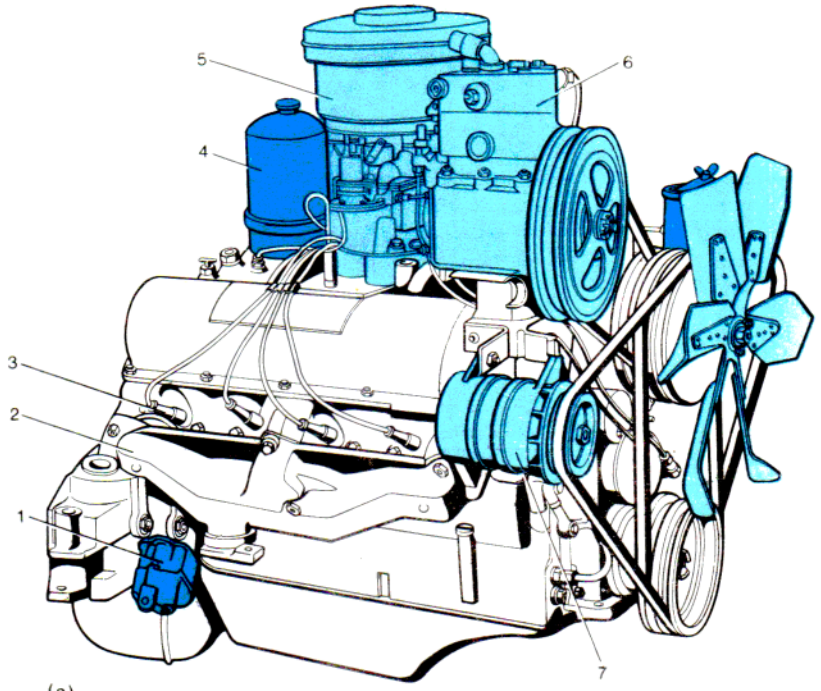
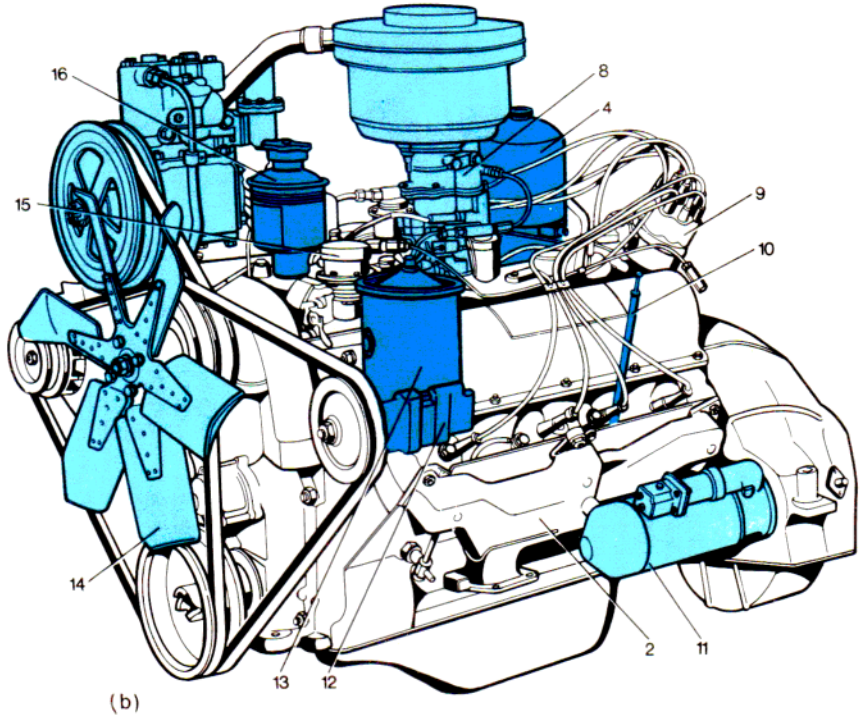
The ЗИЛ-130 Model automobile carburettor engine

(a) right-hand side view;
(b) left-hand side view;
1 – oil pump;
2 – exhaust manifold;
3 – spark plug;
4 – oil filter;
5 – air filter (cleaner);
6 – compressor;
7 – generator;
8 – carburettor;
9 – ignition distributor;
10 – oil level dipstick tube;
11 – starter motor;
12 – hydraulic servo steering pump;
13 – hydraulic oil tank;
14 – fan;
15 – fuel pump;
16 – crankcase ventilation filter



(a)



(b)

tractors, combine harvesters, and automobiles are arranged similarly and include mechanisms and systems performing similar functions.

Diesel engines powering tractors or self-propelled combine harvesters consist of the following mechanisms and systems.

The crank mechanism converts the straight line motion of the pistons into the rotary motion of the crankshaft, which is most convenient for transmitting mechanical energy to rotate the driving wheels or sprockets of tractors or self-propelled combine harvesters and to drive the live attachments of combines and other farm machines.

The timing gear controls the operation of the valves, making it possible to let air into the engine cylinders, compress it to a certain pressure, and purge the exhaust gases from the cylinders at definite positions of the pistons.

The fuel feed system provides for the delivery into the cylinders of metered-out charges of finely atomized fuel at definite moments.

The lubricating system ensures continuous delivery of oil to rubbing components and removal of heat from them.

The cooling system prevents the combustion chamber walls of the engine from overheating and maintains normal temperature conditions in the cylinders.

The starting system is necessary to crank the engine during starting.

The arrangement of component parts of the various systems of a tractor diesel engine is shown in Fig. 12.

THE ENGINES OF COMBINE MODIFICATIONS, i.e., those intended primarily for use on combine harvesters, are brought into line with the base tractor engine models of the same power output.

In contrast to tractor engines, the engines of self-propelled grain combine harvesters are equipped with belt pulleys instead of power takeoff shafts. The front end of the crankshaft carries the drive pulley of the combine driving axle. This pulley is also used to drive the generator, water pump, fan, and hydraulic pumps. The rear end of the crankshaft is connected through a clutch to another shaft which carries a belt pulley for driving the live combine attachments. The operation of the attachments is controlled by means of a lever installed in the combine cab.

All grain combine harvesters are equipped with turbo-charged diesel engines. The engines are started with the aid of an electric starter motor or a starting engine.

In combine harvesters, the engine is mounted on a frame held to the threshing mechanism housing. The engine support cushions used to isolate the threshing mechanism housing from engine vibrations are installed either between the frame and the housing or between the engine supports and the frame.

The mechanisms and systems of AUTOMOBILE CARBURETTOR ENGINES are similar to those of tractor diesel engines. The differences between the former and the latter are as follows:

(a) the fuel feed system of automobile engines is intended to supply the engine cylinders with a homogeneous air-fuel mixture prepared in a special device – the carburettor;

(b) to ignite the combustible charge in the cylinders of carburettor engines, use is made of the ignition system.

The arrangement of component parts of an automobile engine is shown in Fig. 13.

3.5. Basic Engine Performance Characteristics

The basic characteristics describing the performance of an engine are the engine torque, power, fuel economy, and efficiency.

Some of the heat energy evolved in the process of burning of fuel in the cylinders of an engine is converted into mechanical energy. The gas pressure force acting upon the piston is transmitted through the connecting rod to the crankthrow and thus applies torque to the crankshaft.

Torque is the product of the force rotating the crank and the crank radius. Torque is expressed in units of newton meters (N m). While an engine is developing torque, it performs work. The amount of work done in unit time is termed power.

Engine power is measured in kilowatts (kW).

A distinction is made between the indicated power and the effective power of an engine. The indicated power is the power developed by combustion gases in the cylinders of the running engine. The effective, or brake, power is the power that is delivered at the crankshaft. The effective power of an engine is 10 to 12% less than its indicated power, because some power is lost in overcoming friction forces in the engine mechanisms and in driving auxiliary equipment (pumps, fan, generator, etc.). The engine power consumed in overcoming these losses is known as friction power. The engine power increases with the gas pressure force in the cylinder, crankshaft rotation frequency, and engine displacement. The effective power of an engine is given by

$$N_e = \frac{P_e V n}{60\tau}$$

where P_e is the mean effective gas pressure in the cylinder, MPa ($P_e = 0.5$ to 0.8 MPa for four-stroke diesel engines); V is the engine displacement, l; n is the crankshaft rotation frequency, s^{-1}; and τ is the engine cycle factor ($\tau = 2$ for four-stroke engines and $\tau = 1$ for two-stroke engines).

The engine cycle factor is the number showing how many revolutions of the crankshaft it takes to complete the cycle of operations of the engine.

It is seen from the above formula that with τ and P_e remaining the same, the engine power depends on the engine displacement and the crankshaft rotation frequency. Increasing the crankshaft rotation frequency without changing the engine displacement will enhance the power to weight ratio of the tractor or automobile the engine is used on. The running speed of such a tractor or automobile in all gears will increase proportionately with the rotation frequency of the engine crankshaft. It is precisely through augmenting the crankshaft rotation frequencies that the running speeds of farm tractors has recently risen to 2.5-4.16 m/s (9-15 km/h).

Increasing the displacement of an engine increases its overall dimensions. The higher the class of the tractor as regards the drawbar pull, the greater the displacement of the tractor engine, hence its power output.

The mechanical efficiency of an engine is the ratio of its effective (brake) power to indicated power. It depends mainly on the quality of machining and lubrication of the engine components and workmanship in assembling the engine. The numerical value of this characteristic ranges between 0.8 and 0.9.

The thermal efficiency of an engine is the ratio of the amount of heat actually converted by the engine to mechanical energy to the amount of heat contained in the fuel used by it. The thermal efficiency of automobile and tractor engines is in the range from 0.26 to 0.37. In carburettor engines, it tends toward the lower limit and in diesel engines, the upper limit of the range. An engine in good working order converts to effective power around 30% of the thermal energy it receives from its fuel. The rest of the thermal energy is consumed in overcoming mechanical losses (about 10%) and heating the cooling liquid (about 35%) and the engine (about 10%) and is carried away together with the hot exhaust gases (about 15%).

The fuel economy of an engine is characterized by its specific fuel consumption which is determined by dividing the hourly fuel consumption of the engine by its effective power. In diesel engines, the specific fuel consumption does not exceed 72 mkg/J (195 g/e.h.p.h). An engine with worn, improperly adjusted, or poorly lubricated rubbing parts will have its power output and fuel economy reduced.

Review Questions

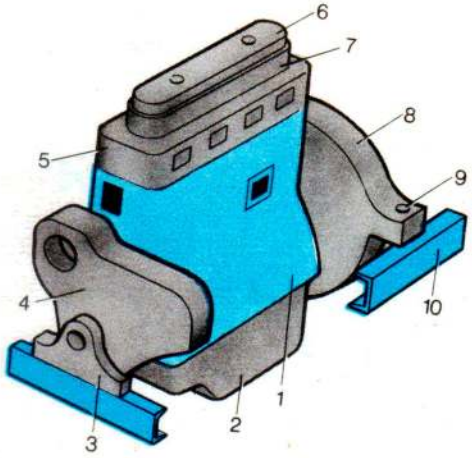
1. According to what basic features are automotive engines classified?
2. What are the physical laws underlying the operation of the internal combustion engine?
3. What are the component parts a simple engine consists of?
4. What is the compression chamber?
5. What is the compression ratio?
6. What are the processes that take place in the engine cylinder?

7. What is the firing order of the four-cylinder four-stroke engine?

8. Name the basic mechanisms and systems of an engine.

9. What are the factors defining the engine fuel economy?

10. What does the power output of an engine depend on?



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In-line engine structure

1 – cylinder-block-and-crankcase unit of monoblock construction;
2 – oil pan (sump);
3 – engine front support;
4 – timing case;
5 – cylinder head;
6 – valve cover;
7 – cylinder head cover;
8 – flywheel (bell) housing;
9 – engine rear support;
10 – tractor frame

Chapter 4
Crank Mechanism

4.1. Engine Framework

The engine framework serves as an enclosure and a support for all the component parts of the engine mechanisms and systems.

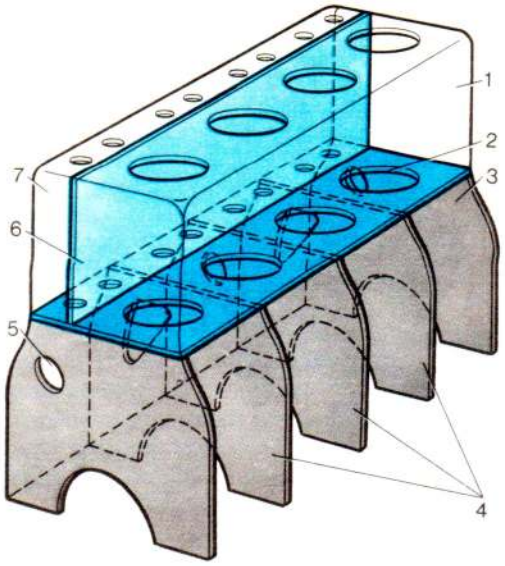
The framework of automotive engines is formed by a number of components that are rigidly held together (Fig. 14). Depending on the engine type and power output, these structural components do have some constructional differences, but in principle they are similar in all engines.

The main structural component of a multicylinder engine is the cylinder-block-and-crankcase unit.

THE CYLINDER-BLOCK-AND-CRANKCASE UNIT (Fig. 15) of most modern in-line cylinder engines is a one-piece box-like casting, this combination generally being termed monoblock construction. To improve its rigidity and divide it into several compartments, or chambers, the unit is fabricated with inner partitions, or bulkheads. Horizontal partition, or lower deck of the cylinder block *2* divides the unit into approximately equal halves: the upper half – cylinder block *1* – and the lower half – crankcase *3*. The cylinder block houses cylinder liners, or sleeves, that tightly fit into bores in the upper and lower decks of the block, the upper deck being usually referred to as the cylinder deck. Solid vertical partition *6* passing along one of the sides of the cylinder block separates push-rod, or tappet, chamber *7* from the water (coolant) jacket.

The space between the vertical partition, cylinder block walls, and cylinder liners is filled with water and forms a water jacket. The crankcase is broadened so as to accommodate the crankshaft throws. With this type of construction, the crankshaft is underslung in the crankcase and supported by crankcase (or main bearing) bulkheads *4* that form a series of crank chambers. The upper main bearing halves are carried directly in saddles *7* (Fig. 16 *a*) formed in these bulkheads, while detachable inverted bearing caps *6* accommodate the lower main bearing halves. In the crankcase bulkheads, on the side nearest the tappet chamber, there are bores *9* for camshaft bearings.

Rubber sealing rings *8* grooved into the lower deck of the cylinder block serve to prevent the leakage of coolant from the cylinder



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Schematic diagram of the cylinder-block-and-crankcase unit of an in-line engine

1 – cylinder block;
2 – horizontal partition (lower deck);
3 – crankcase;
4 – crankcase partitions (bulkheads);
5 – camshaft bearing bore;
6 – vertical partition;
7 – push-rod (tappet) chamber

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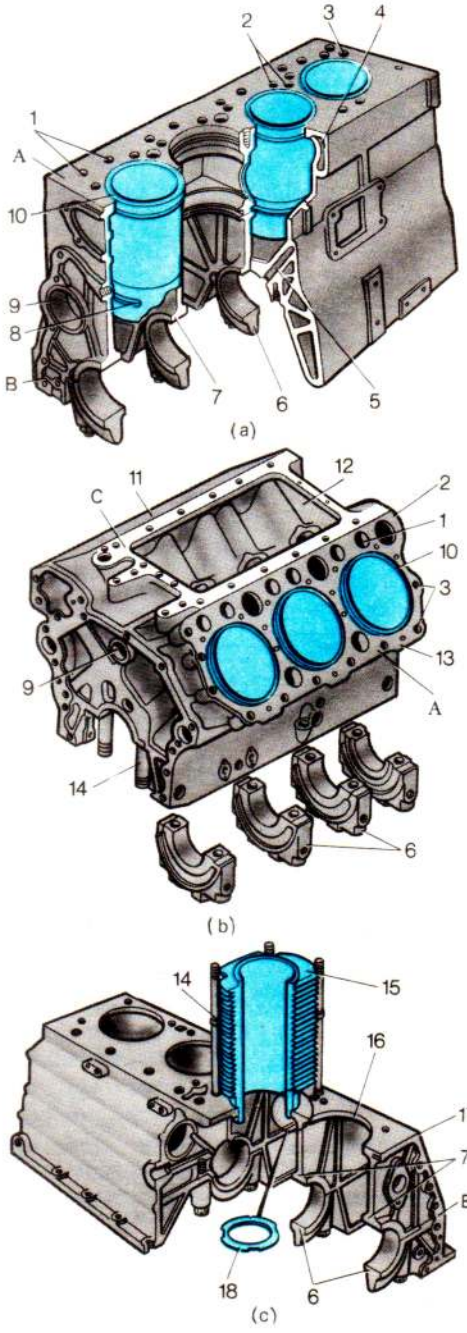
Cylinder-block-and-crankcase units of tractor engines

(a) liquid-cooled in-line engine;
(b) liquid-cooled V-type engine;
(c) air-cooled engine;
1 – push-rod holes;
2 – water holes;
3 – cylinder head stud holes;
4 – water passage;
5 – oil passage;
6 – crankshaft (main) bearing caps;
7 – bearing saddle;
8 – rubber sealing ring;
9 – camshaft bearing bore;
10 – cylinder liner (sleeve);
11 and 13 – left- and right-hand cylinder banks, respectively;
12 – tappet chamber;
14 – stud;
15 – air-cooled cylinder barrel;
16 – cylinder liner bore;
17 – crankcase;
18 – sealing gasket;
A – cylinder deck;
B – timing case mounting pad;
C – tappet cover and turbocompressor (supercharger) mounting pad



block jacket into the crankcase and also to avoid crankcase oil finding its way into the cooling system. The cylinder block jacket communicates with the cylinder head jacket via holes *2* in the cylinder deck. The deck is also provided with threaded holes *3* for the studs that hold the cylinder head down to the cylinder block and holes *1* for the push-rods. In the cylinder block, there are cast passages *4* intended to deliver water from the water pump into the block and drilled holes and passages 5, to supply oil to some wearing component parts of the engine.

Cylinder banks *11* and *13* of the cylinder-block-and-crankcase unit of a V-type engine (Fig. 16 *b*) accommodate cylinder liners *10* and are integrated by a common water jacket. In the center of the unit, there are bores *9* for the camshaft bearings. Main bearing caps *6* are held to the bearing saddles in the crankcase bulkheads by studs *14* and nuts. The cylinder heads are mounted on plane A (cylinder decks) of the cylinder banks.

As distinct from liquid-cooled engines, there is no cylinder-block-and-crankcase unit in air-cooled engines, all the egine components being carried by cast crankcase *17* (Fig. 16 *c*). In the top deck of the crankcase, there are bores *16* to fit cylinder barrels *15*. The cylinder barrels together with cylinder heads are held down to the crankcase deck by special studs *14* and nuts, copper sealing gaskets *18* being placed between the barrels and the crankcase. The crankcase accommodates both the crankshaft and camshaft, as is the case with liquid-cooled engines.

On the outside of any cylinder-block-and-crankcase unit, there are machined bosses and pads with threaded holes for mounting various engine units and assemblies. Positive sealing arrangements, such as gaskets or seals, are used between the joint faces of the cylinder-block-and-crankcase unit and the engine components mounted on it, so that the leakage of coolant or oil may be prevented and dirt finding its way into the unit avoided. Attached to the cylinder-block-and-crankcase unit are also the other structural components of the engine: the cylinder head at the top, the flywheel (bell) housing at the rear end, the timing case at the front end, and the sump at the bottom.

CYLINDER HEAD 7 (Fig. 17) of a multicylinder engine is a robust iron casting resembling a thick plate that covers the cylinder block. The lower deck of the head is carefully machined and forms the top wall of the combustion chambers of all the four cylinders. The cylinder head is provided with openings for the valves, fuel injectors, and push-rods and also with intake ports *1* and exhaust ports *4* and *22*. The space between the ports and the cylinder head walls is filled with water and forms what is known as water jacket *6*. To prevent the leakage of combustion gases and water, metal-asbestos gasket *21* is placed between the cylinder head and block.

The openings in the gasket are edged in sheet steel where the gasket surrounds the cylinder liners and the oil passage to the valve mechanism (pipe *23*).

The valve mechanism is mounted on the top deck of the cylinder head and is enclosed by the cylinder head cover and valve cover *5*. Breather *3* fitted in the valve cover makes it possible for the crankcase to communicate with the atmosphere. The breather lets out combustion gases and air that have forced their way into the crankcase from the cylinders and thus prevents crankcase oil being squeezed out through the various engine seals. It also lets the atmospheric air in the crankcase if the pressure of the air cooling in the crankcase after the engine has stopped should fall below atmospheric pressure. The oil-soaked wire-mesh stuffing of the breather cleans the air entering the crankcase from dust. In some engines, the crankcase breather is mounted on the cylinder block side wall nearest the tappet chamber or in the oil filler cap. Most carburettor engines use a forced (closed) system of crankcase ventilation which ensures a more positive removal of the harmful blow-by combustion gases and fuel vapours from the crankcase.

In air-cooled engines, each cylinder has a head of its own. The external surface of the cylinder head is in this case provided with cooling fins.

Oil pan (sump) *15* fixed to the

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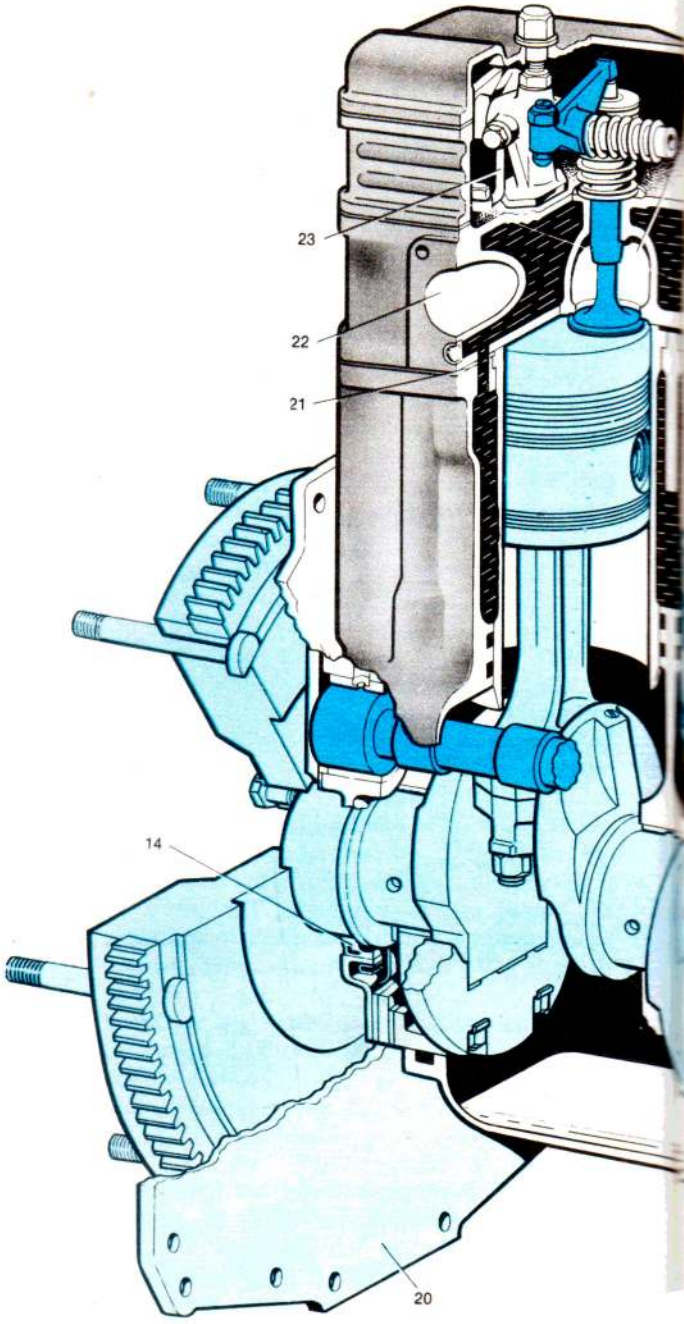
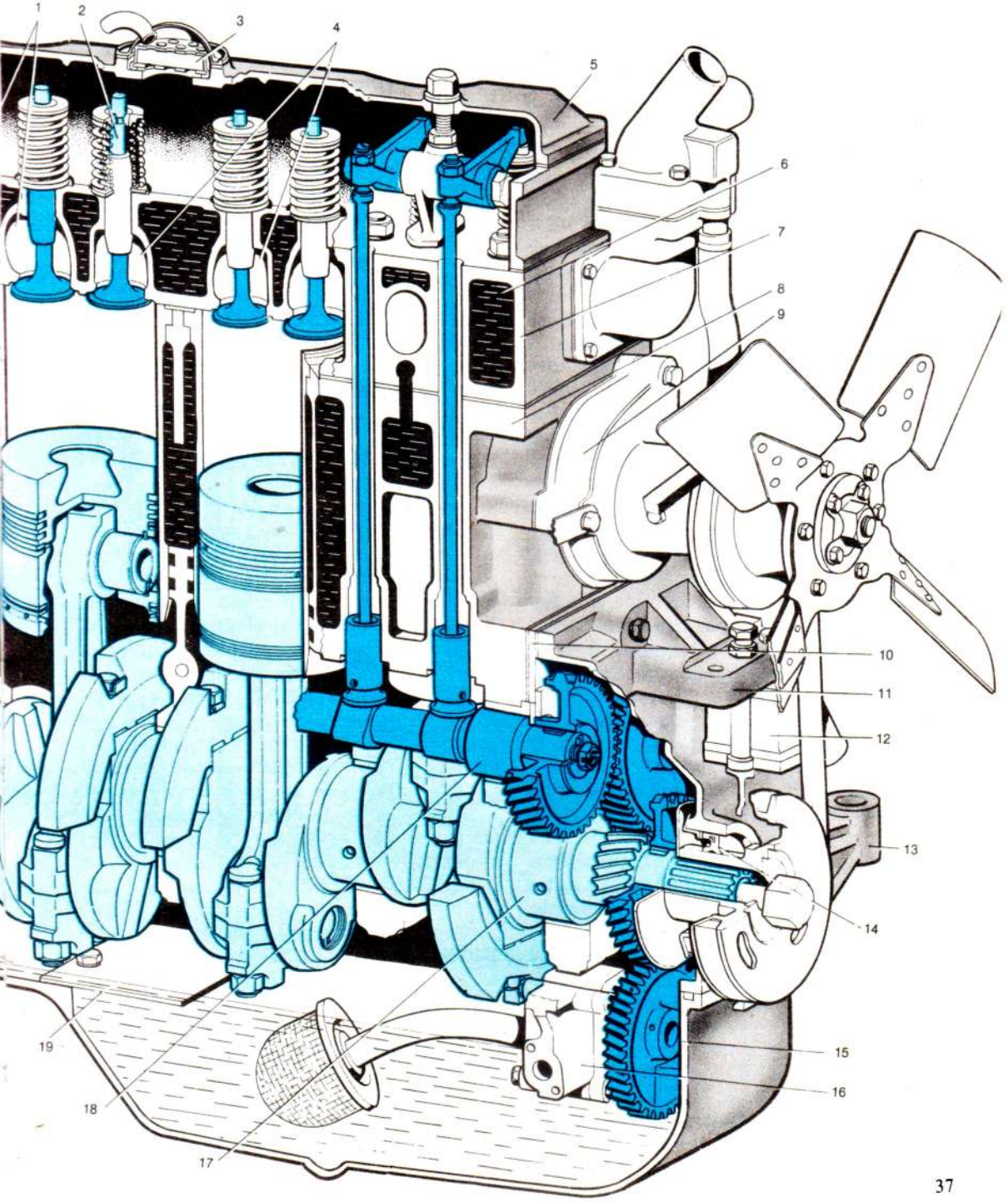
The Д–240 Model in-line diesel engine

1 – intake ports of the third and fourth cylinders;
2 – valve;
3 – breather;
4 – exhaust ports of the second and third cylinders;
5 – valve cover;
6 – water jacket;
7 – cylinder head;
8 – cylinder-block-and-crankcase unit;
9 – water pump;
10 – timing case adaptor plate;
11 – engine front support;
12 – engine support cushion;
13 – engine front support bracket;
14 – crankshaft radial lip rubber seals;
15 – oil pan;
16 – oil pump;
17 – crankshaft;
18 – camshaft;
19 – baffle plate;
20 – rear adaptor plate;
21 – metal-asbestos gasket;
22 – exhaust port of the fourth cylinder;
23 – oil-feed pipe to valve mechanism

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cylinder-block-and-crankcase unit from below serves as an oil reservoir and a closure for the lower part of the engine. The crankcase to oil pan joint is sealed by a cork or rubberized asbestos fabric gasket. The oil pan is provided with baffle plate *19* to lessen the tendency of the crankcase oil to splash during the operation of the tractor. The timing case cast integral with engine front support *11* encloses the gears that transmit rotation from crankshaft *17* to camshaft *18* and also drive the fuel pump, hydraulic pump (not shown in the figure) and oil pump *16*.

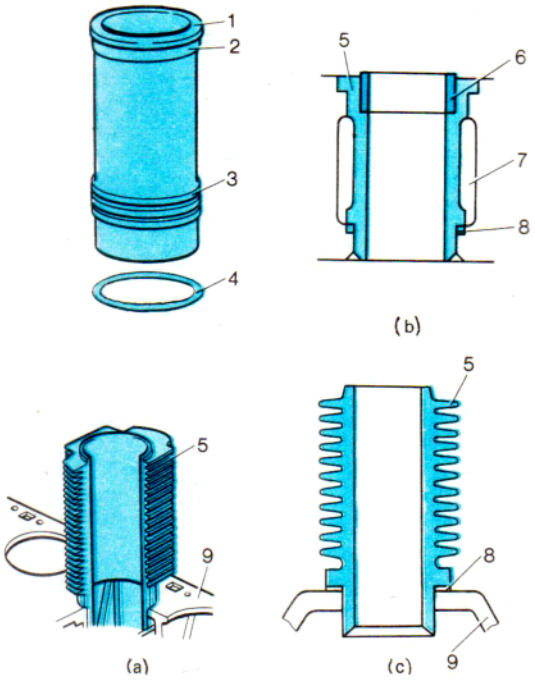
ENGINE MOUNTING. Engine front support *11* is fixed, through the intermediary of metal-rubber engine support cushion (or mount) *12*, to support bracket *13* that is held to the tractor frame. The support cushion reduces the vibration level of the engine and the tractor framework. At the rear, the engine is fastened to the transmission case through the intermediary of steel adaptor plate *20*. Such an engine mounting system is known as the three-point mounting. Also known are four-point, six-point, and cantilever engine mounting systems. In the case of a cantilever mounting (e. g., in self-propelled carriers), the rear part of the engine is rigidly fastened to the transmission case, the engine front having no support at all. With a six-point mounting, the engine rests on the tractor frame, using six elastic metal-rubber mounts, of which two are installed at the front of the engine and the other four, at the rear. The engine rear support mounts are located on the flywheel (bell) housing.

THE BELL HOUSING serves to accommodate the flywheel and to mount the engine on the tractor frame. It also provides mounting points for a number of units (e. g., the starting engine and reduction gear). In some engines, the flywheel housing is provided with means (e. g., a timing pointer) to locate the piston of the first cylinder at its top dead center for timing purposes.

The structural components, except for the oil pan, of tractor engines are usually cast in iron, whilst those of some automobile engines use an aluminium alloy.

4.2. Cylinders and Pistons

CYLINDERS of the automotive engines are of detachable (insertion) type, *cylinder liners* (Fig. 18), which increases the service life of the cylinder-block-and-crankcase unit, since worn liners can fairly easily be renewed. Cylinder liners are made of an alloy cast iron. The inner surface of the cylinder liner, called the face, is thoroughly machined and hardened. According to their bore, i. e., the inside diameter, cylinder liners are classified in three size groups: Б, С, and М (large, medium, and small). The size group marking is punched in the end face of collar *1* of the cylinder liner.



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Cylinders

(a) wet cylinder liner;
(b) illustrating the installation of a cylinder liner in an automobile engine;
(c) air-cooled cylinder;
1 – collar;
2 – top retaining flange;
3 – bottom retaining flange;
4 – rubber sealing ring;
5 – cylinder barrel;
6 – insert;
7 – water jacket;
8 – sealing gasket;
9 – crankcase

Cylinder liners whose outer surface is exposed to the coolant in the cylinder jacket are of what is known as the wet variety (Fig. 18 *a*). The outer wall of the wet liner is made to have two retaining flanges *2* and *3* that provide for the liner to fit tightly in the cylinder block. Rubber sealing rings *4* installed between the lower retaining flange of the cylinder liner and the cylinder block prevent the leakage of coolant from the cylinder jacket into the crankcase. In some engines, these rings are grooved into the retaining flange, while in others they are grooved into the cylinder block. Cylinder liners are generally fitted so that their top end face protrudes a little above the top deck of the cylinder block, which ensures a better compression of the metal-asbestos cylinder head gasket, and thus creates an efficient seal against combustion gases escaping from the cylinder. The amount of protrusion is usually termed the nip of the cylinder liner. The cylinder liners of some automobile engines are fitted with wear-resistant inserts *6* (Fig. 18 *b*) of anticorrosion cast iron in order to reduce wear on the top part of the liners. In some engines, annular copper gasket *8* is placed between the bearing surface of the lower retaining flange of the cylinder liner and its seating in the lower deck of the cylinder block.

The cylinder barrels of air-cooled engines (Fig. 18 *c*) are provided with cooling fins on the outside. In the lower part of the cylinder barrel, there is a retaining flange that rests against the crankcase deck. A copper ring is used between the flange and the deck. Each cylinder, together with its head, is clamped to the crankcase by means of special (anchor) studs and nuts.

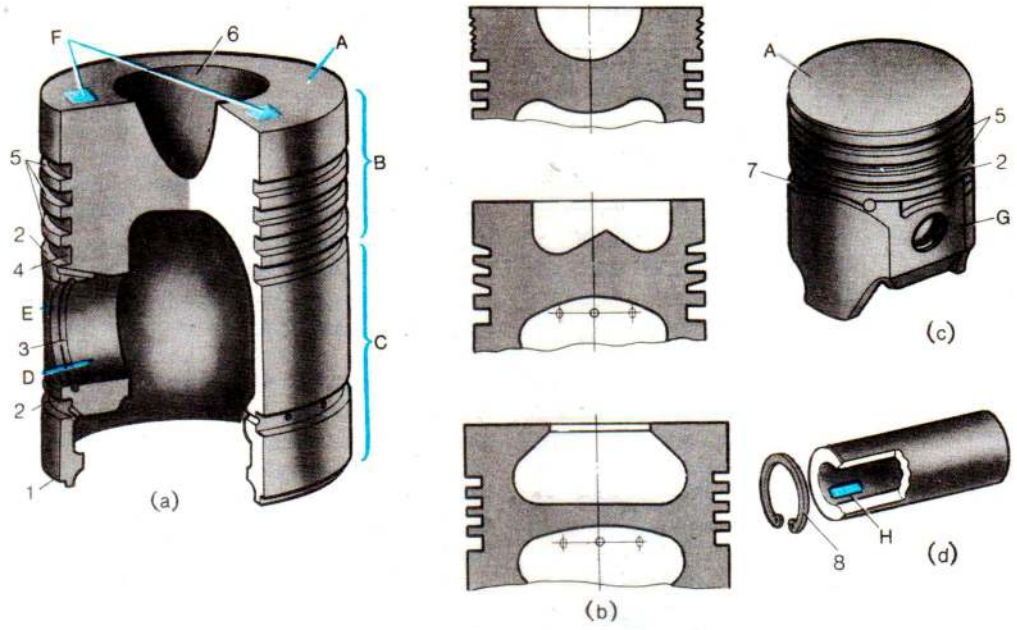
THE PISTONS (Fig. 19) take up and transmit to their connecting rods the forces resulting from the gas pressure in the cylinders, and also participate in all the operations constituting the working cycle of the engine. The pistons are exposed to high temperatures and pressures, and move with significant velocities inside the cylinders. Accordingly, their material must be adequately strong and wear-resistant; it must be light in weight and conduct heat well. Therefore, the pistons in modern engines are cast in a light-weight, but sufficiently strong aluminium alloy.

The piston (Fig. 19 *a*) resembles an inverted cup. It consists of crown, or top, *A*, head (or sealing part) *B*, and guiding part *C*, referred to as the piston skirt. The pistons of diesel engines (Fig. 19 *b*) are made with recesses (cavities) in their tops, whose shape depends on the method of mixing the fuel with air and the arrangement of the valves and fuel injectors. Such a specially shaped piston top facilitates the mixing of the fuel entering the cylinder with the air contained therein, thus promoting its fuller burning.

The outer surface of the piston head and skirt is provided with grooves *5* and *2* to accommodate compression and oil-control rings, respectively. The number of the rings installed on a piston depends on the engine type and the crankshaft rotation frequency. In some engines, a metallic-bonded steel groove insert is used for the top compression ring in order to improve the wear resistance of the ring-to-groove joint, and thus increase its durability. Oil-ring grooves have through holes drilled in their backs around the periphery of the piston to drain the oil scraped off by the rings into the engine crankcase.

On the inside of the piston skirt, there are two bosses *D* with holes to fit the piston pin (also known as the gudgeon, or wrist, pin). The piston pin bosses are joined with the piston crown by intermediate supporting webs, which improves the strength of the piston. Annular grooves *3* cut in the pin holes serve to accommodate piston pin lock rings, or retainers, *8*. The piston skirt is relieved on the outside opposite the piston pin bosses, so that oil pockets – "coolers" – are formed where oil is accumulated to facilitate the cooling of the thickened part of the piston and prevent it from becoming stuck in the cylinder. The latter end is also attained with pistons machined to a special form, which is both tapered in profile (the skirt diameter is greater than the head diameter) and oval in contour (the major axis of the skirt is disposed in the direction across the piston pin).

According to the outside diameter of the skirt, pistons are classified in three size groups marked Б, С, and М (large, medium, and small).



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Pistons

(a) piston of a tractor diesel engine;
(b) cross-sections through tractor engine pistons;
(c) piston of an automobile carburettor engine;
(d) piston pin;
1 – oil-scraping edge;
2 – oil-ring groove;
3 – lock ring groove;
4 – oil holes to lubricate piston pin;
5 – compression-ring grooves;
6 – combustion chamber bowl;
7 – compensating slot;
8 – piston pin lock ring (circlip);
A – piston top (crown);
B – piston head;
C – piston skirt;
D – piston pin bosses;
E – skirt relief ("cooler");
F – piston mass and size group markings;
G – piston installation marking;
H – piston pin size group marking

The size group markings are punched in the piston crown. When assembling an engine, it is necessary to see to it that the pistons are the same size group as the cylinder liners.

Pistons are also classified in two size groups by the pin hole diameter and marked in paint (black or yellow) on the piston pin bosses.

The pistons of some tractor engines are made with shallow (0.3 mm deep) annular grooves in the head (see Fig. 19 *b*). These grooves trap the carbon resulting from the burning of oil, and thus prevent premature seizure of the piston rings.

Carburettor engines use flat-topped pistons (Fig. 19 *c*). Such pistons have found extensive application, for they are fairly simple to manufacture and run colder than other piston types. In some automobile engines, the piston skirt is partially cut away below the piston pin bosses in order to provide for the free passage of the crankshaft counterweights past the piston at BDC and to reduce the weight of the piston. The pistons have part-circumferential compensating slots 7 beneath the head, and their skirt may incorporate a near vertical or a T-shaped compensating slot. The slots increase the flexibility of the piston skirt, which eliminates the danger of the piston seizure in the cylinder. Where the pistons have split skirts, they are installed in the engine so that the side thrust arising from the connecting rod angularity on the power stroke is taken by the

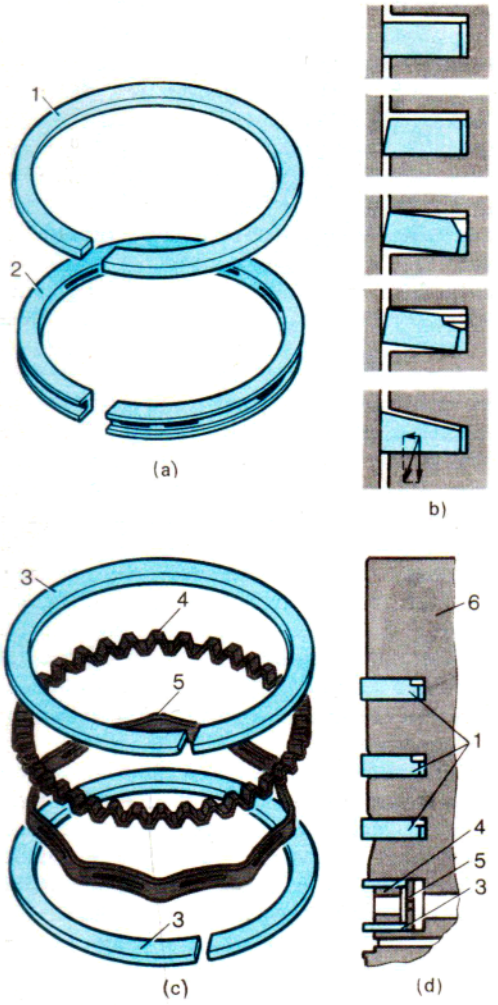
solid part of the piston. A marking inscribed on the skirt helps install the piston correctly in the engine.

PISTON PINS (Fig. 19*d*) are hollow and are made of steel. The piston pin is kept from axial movement by internal spring lock rings, or circlips, *8* that are expanded into grooves in the piston pin bosses. The piston pin connects the piston with its connecting rod. The assembly fits are normally such that the pin has a clearance in the connecting rod small end bush and an interference in the piston bosses. During operation of the engine, as the normal running temperature is reached, a clearance appears in the piston boss-to-pin joints because of the different linear expansion coefficients of the piston and pin materials, and so the pin becomes free to turn in the piston bosses. Such a piston pin is known as the fully floating type.

Piston pins are classified according to the outside diameter in two size groups which are marked, as is the case with the pin holes in the piston bosses, in black or yellow paint on the inner surface of the pins. When attaching pistons to their connecting rods, it is necessary to see to it that the piston pins are the same size group as the pistons.

PISTON RINGS (Fig. 20) create a gas-tight sliding seal between the piston and cylinder. According to purpose, the rings are classed into compression rings *1* and oil-control rings *2*. The compression rings maintain an effective seal against combustion gases leaking past the piston into the crankcase, while the oil-control rings prevent the crankcase oil from getting into the combustion chamber, scraping all oil surplus to that required for proper lubrication of the piston and cylinder combination of the cylinder wall.

Piston rings are made of an alloy cast iron or steel. The outside diameter of the rings is greater than the cylinder bore, and they are necessarily cut through at one point, so that they may be installed in their grooves in the piston and are free to exert an initial pressure against the cylinder wall and tightly fit it when compressed into the cylinder. The cut in the piston ring is termed the piston ring joint. Piston ring joints may be of a simple butt, bevel



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Piston rings

(a) outside view;
(b) cross-sectional shapes of compression rings in working position;
(c) composite oil-control ring;
(d) arrangement of rings on a piston;
1 – compression ring;
2 – oil-control ring;
3 – flat steel rings (rails);
4 – axial spring expander;
5 – radial spring expander;
6 – piston

(tapered), or seal-cut type. Butt joint piston rings are the most common type used in automotive engines, for they are the most simple and the least costly to manufacture. To lessen the leakage of combustion gases through the gaps in the piston ring joints, termed simply the ring gaps, the rings are installed on the piston so that their joints are on the opposite sides of the piston, preferably equally spaced around the piston circumference. Two or three compression rings are enough to provide an effective combustion chamber seal in carburettor engines, whereas in diesel engines, where combustion pressures are higher, three or four such rings are commonly used on a piston. Piston rings are assembled in their grooves so that they have a small clearance and are free to move relative to the piston. If the rings poorly fit the cylinder walls, combustion gases will leak through gaps between the rings and the cylinder face and cause the rings to overheat. The resulting carbon deposits will fill the piston ring side clearances, and the rings will stop moving freely in their grooves and exerting the necessary pressure against the cylinder walls. This phenomenon, known as the seizure or sticking, of piston rings, is attended by a loss of engine power and an increased oil consumption.

Compression rings may have various cross-sectional shapes (Fig. 20 *b*). As compared with the rings of plain rectangular section, taper-faced, or bevel, rings have a smaller contact area, which ensures their quick bedding in to and good contact with the cylinder face over its entire periphery. In some engines, compression rings have their inner upper corner chamfered or counterbored. When compressed into the cylinder, such rings tend to deform (twist) and put their sharp bottom edge against the cylinder face. Therefore, these rings, known as the twist-type (torsional) piston rings, operate similar to the taper-faced rings, but at the same time, they move less in the axial direction relative to the piston. A trapezoidal cross-sectional shape of piston rings (rings of such section are known as the keystone type) lessens the possibility of the rings sticking in their grooves in the case of heavy carbonization and improves the contact between the rings and the cylinder walls.

The working face of the top compression ring is chromium plated in order to extend the useful life of all the piston rings and the cylinder liner. Many engines have their piston rings tinned to improve their bedding-in conditions.

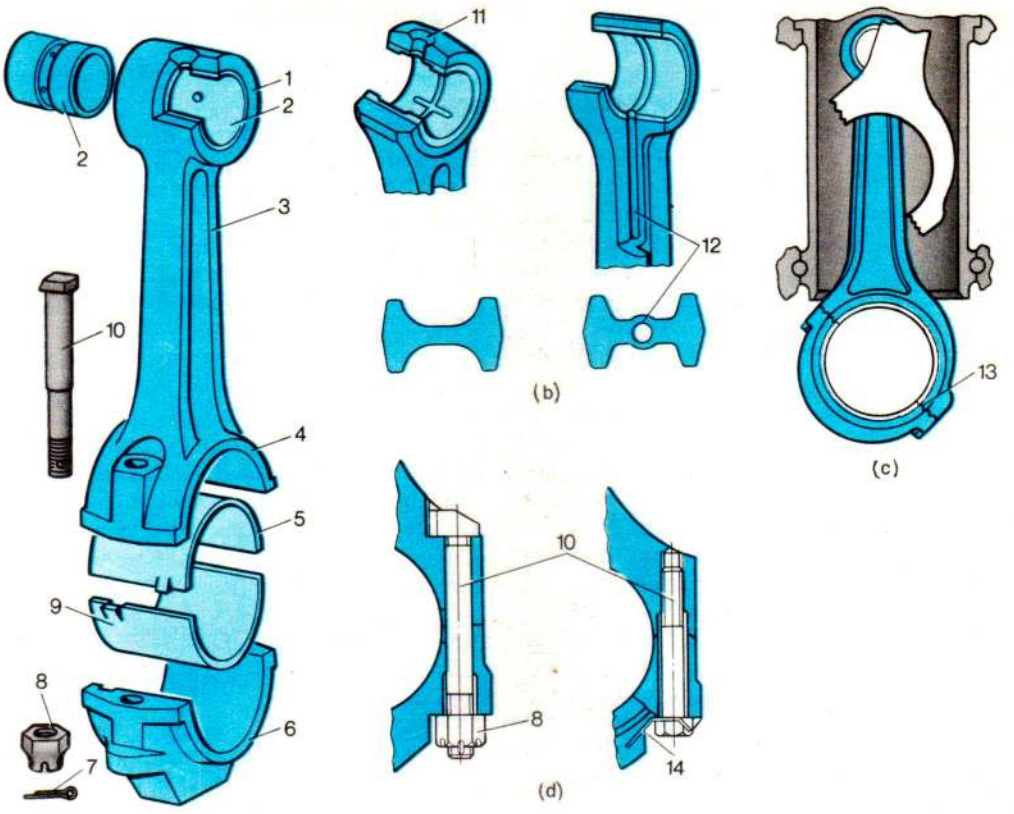
The oil-control rings (one or two such rings may be used on a piston) are installed below the compression rings. In contrast to the latter, these rings either have through slots machined in them radially or consist of two scraper-type rings. Some engines use composite oil-control rings (Fig. 20 *c*) comprising two flat steel rings, called rails, and two spring expanders – one axial and the other radial type. The axial expander is a wave form spring compressed between the rails to press them against the sides of the ring groove, whereas the radial-type expander is a polygonal shape spring strip which is compressed between the inner edges of the rails and the back of the groove to press the rails radially against the cylinder face.

The composite-type oil-control rings tightly fit the cylinder walls and provide for a low oil consumption.

4.3. Connecting Rods and Crankshaft

THE CONNECTING RODS (Fig. 21 *a*) link the pistons with the crankshaft and transmit to it the loads arising from the combustion gas pressure taken by the pistons. In operation, the connecting rod is subjected to both gas pressure and inertia loads, and therefore, it must be adequately strong and rigid and light in weight as well. Connecting rods are generally fabricated from a high-quality steel in the form of a bar with ring-shaped heads at its ends, the heads being known as the connecting rod big end and small end and serving to attach the rod to the crankpin and the gudgeon pin of the piston, respectively.

Shank, or blade, *3* of the connecting rod is provided with an I-cross section to give the rod maximum rigidity with the minimum of weight. The connecting rod small end is made in the form of a continuous eye into which bronze bush *2* is pressed so as to provide an



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Connecting rods

(a) connecting rod components;
(b) cross-sections through connecting rod shanks (blades) and methods of feeding oil to piston pin;
(c) angled connecting rod big end;
(d) methods of locating connecting rod cap;
1 – connecting rod small end;
2 – connecting rod bush;
3 – connecting rod shank (blade);
4 – connecting rod big end;
5 – connecting rod bearing half-liner (insert);
6 – connecting rod cap;
7 – cotter pin;
8 – horned nut;
9 – locating lug;
10 – connecting rod bolt;
11 – oil hole;
12 – oil passage;
13 – serrated joint;
14 – tab washer

interference fit, whereas the big end of the rod is split into two halves with the upper half integral with the rod shank and the lower half in the form of detachable cap *6*.

The bore in the connecting rod big end is machined after the cap is assembled on the rod. Therefore, the rod caps must not be interchanged. To avoid misplacing the rod caps during assembly, the connecting rods and their mating caps are marked on one side with serial numbers, starting with the first rod from the radiator, to identify their location in the engine.

Both halves of the connecting rod big end are joined by means of special high-strength bolts *10* and nuts. The nuts on the connecting rod bolts are tightened with a torque indicating

wrench and then cottered. The connecting rod big end houses a sliding contact bearing comprising two half-liners, or inserts, *5*. The half-liners are kept from shifting endwise or rotating by locating lugs, or locking lips, 9 that nestle in special slots provided in the housing on one side of the rod. The connecting rod big end of automobile engines features a hole through which oil is squirted onto the cylinder walls.

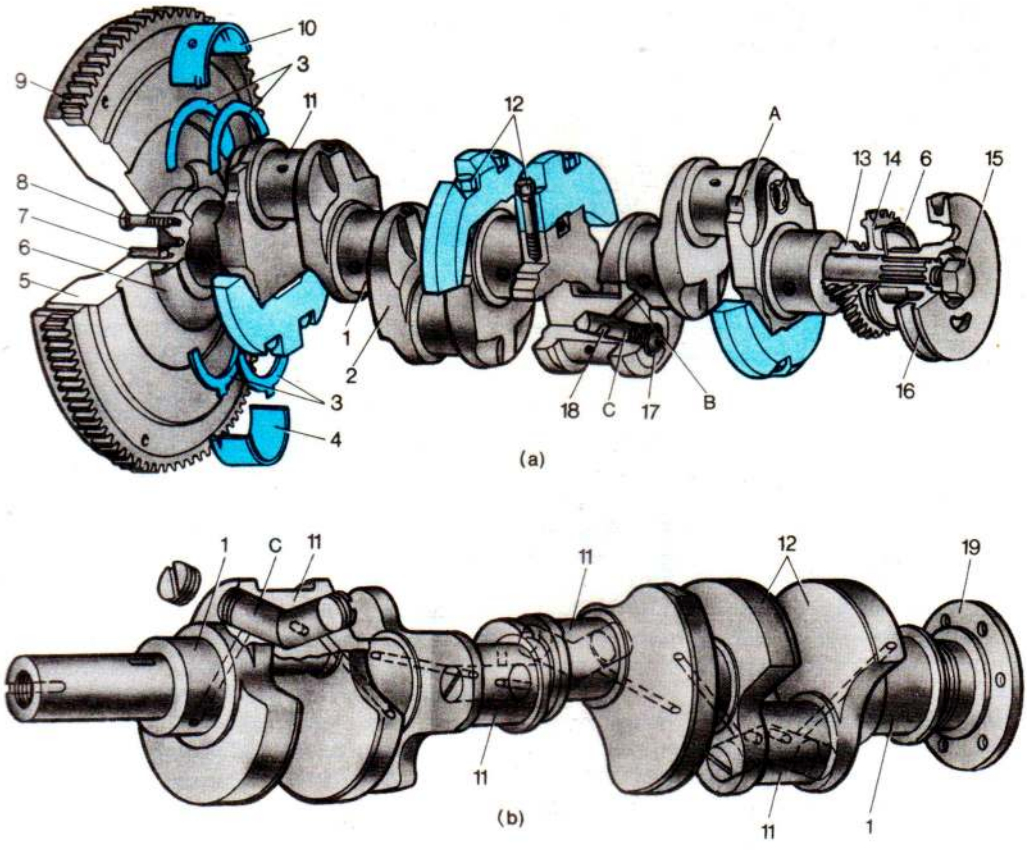
The oil necessary to lubricate the piston pin is supplied either through oil hole *11* (Fig. 21 *b*) or via oil passage *12* drilled through the connecting rod shank.

The parting line between the connecting rod and its cap is generally arranged at right angle to the axis of the shank, but in some engines, the parting line is necessarily arranged diagonally, because the proportions of the connecting rod big end are such that the lower part of the rod could not otherwise be passed through the cylinder for assembly purposes. With such an angled big end (Fig. 21 *c*), the cap is secured to the connecting rod by setscrews instead of bolts and nuts. To resist the greater tendency for the inertia forces to displace the cap sideways relative to the connecting rod, either a serrated or a stepped joint is generally preferred for their abutting faces. Hence, the retaining setscrews in their clearance holes are completely relieved of shear loads. Tab washers *14* (Fig. 21 *d*) are used under the heads of setscrews in order to prevent the latter from working loose.

THE CRANKSHAFT (Fig. 22) takes the downward thrusts of the pistons and connecting rods when the fuel-air mixture is burned in the cylinders and changes these thrusts into torque which is transferred to the drive line of the tractor or automobile; it also drives various engine mechanisms and components. The periodic gas pressure and inertia forces taken by the crankshaft may cause it to suffer wear and bending and torsional strains. The crankshaft therefore must be adequately strong and wear-resistant.

The crankshaft is either forged from a high-quality steel or cast in a high-strength iron. It consists of main bearing journals *1*, crankpins *11*, webs, or cheeks, *2* that connect the journals and crankpins together, a nose (front end), and a shank (rear end). Counterbalance weights *12* necessary for balancing the crankshaft are either formed integrally with, or attached separately to, the crank webs. The main bearing journals and crankpins are induction hardened to improve their wear resistance. Drilled diagonally through the crank webs are oil holes to supply oil to the crankpins. The crankpins are bored hollow in order to reduce the crankshaft inertia. The open ends (or end where angular blind holes are necessary to clear counterbalance weights) are sealed by screw plugs *17*, since the hollow interior *C* of each crankpin also acts as an oil supply duct for big-end lubrication and as a centrifugal oil cleaner. With the crankshaft rotating, mechanical impurities (wear products) contained in the oil inside the hollow crankpins settle on the crankpin interior walls under the action of centrifugal forces. In V-type engines, each crankpin has two connecting rods assembled on it, and therefore, the crankpins here are longer than in in-line cylinder engines. The crankshaft front end carries one or two gears for driving the valve mechanism and also other engine mechanisms, fan drive pulley *16*, and a starting crank jaw (ratchet) or bolt *15*. Mounted between the crankshaft pulley and gear is oil slinger *6* that throws oil away from the crankshaft front bearing seal. In some engines, the crankshaft gear is carried on the rear end of the shaft.

Attached to the rear end of crankshaft is flywheel *5*. In some engines, the flywheel is located relative to the crankshaft by dowels *7* and clamped firmly to the rear face of the shaft by a ring of bolts *8* screwing direct into the shaft end. Other engines have their crankshafts provided with flange *19* in which holes are drilled for securing the flywheel. In front of the flange, the crankshaft is provided with an oil-return thread which, in conjunction with a close clearance plain bore housing, forms a labyrinth-type seal operating upon the Archimedean screw pump principle to oppose the leakage of oil into the bell housing. The rear end of the crankshaft usually carries a thrust



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Crankshafts

(a) of in-line tractor engine;
(b) of V-type automobile engine;
1 – main bearing journal;
2 – web (cheek);
3 – thrust half-washers;
4 – main bearing cap insert;
5 – flywheel;
6 – oil slinger;
7 – dowel;
8 – flywheel bolt;
9 – flywheel ring gear;
10 – main bearing saddle insert;
11 – crankpin;
12 – counterbalance weights;
13 – crankshaft gear;
14 – oil pump drive gear;
15 – bolt;
16 – fan drive pulley;
17 – screw plug;
18 – clean oil outlet tube;
19 – crankshaft flange;
A – crankpin size group marking;
B – oilway to crankpin hollow interior;
C – crankpin hollow interior

collar which serves to prevent the shaft from moving endwise. For this purpose, the rear main bearing is provided either with integral flanges on both its sides to serve as thrust faces or with separate semicircular thrust washers *3*. The endwise movement of the crankshaft in some engines is restricted by similar thrust bearing arrangements embracing either the front or one of the intermediate main bearing journals.

The main bearings, like the crankpin bearings, take the form of half-liners, or inserts, *4* and *10* made of a steel-aluminium bimetal band comprising a steel backing to which is bonded a thin layer of an antifriction alloy capable of withstanding heavy loads and possessing a high wear resistance. To improve

their embeddability, the half-liners are tinned on the inside. The half-liners of both the crankpin bearings and most of the main bearings are interchangeable.

THE FLYWHEEL contributes to the uniform rotation of the crankshaft and helps the engine overcome increased loads when starting the tractor from rest and also during operation. The flywheel is a heavy disc of cast iron. Since the flywheel also serves to form part of the clutch, its rear face is thoroughly machined. In the front face of the flywheel, there is a shallow indentation used to determine the position of the piston in the first cylinder. When this indentation is aligned with a special hole provided in the bell housing, the piston is at TDC. In some engines, this indentation indicates the start of fuel injection into the first cylinder. The flywheels of some engines also carry marks indicating the serial numbers of the cylinders where the compression stroke occurs. The flywheel marks and indentation are used for setting the valve and ignition systems relative to prescribed positions of the crankshaft.

Pressed on, or bolted to, the flywheel rim is ring gear *9* which serves to impart rotation to the crankshaft from a starting device or a starter motor when starting the engine.

4.4. Engine Balancing

During operation of the engine, the crank mechanism components are acted upon by various forces that change both in magnitude and in direction. Some of the forces are useful and provide for the engine to operate, while others are harmful and cause undue wear of the engine component parts.

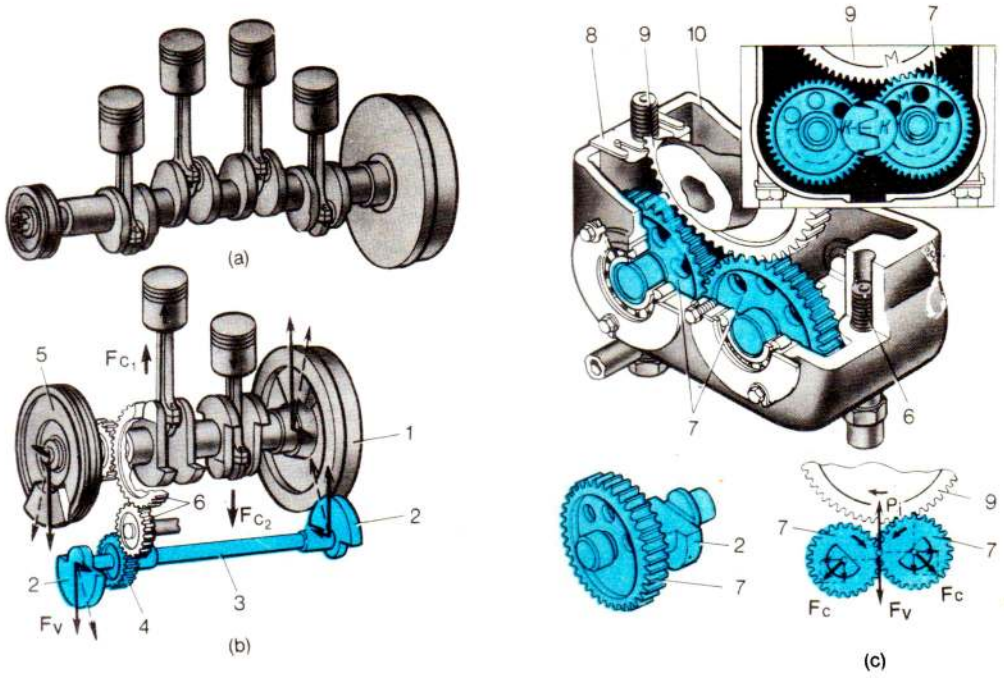
The useful forces are those generated by the gas pressure in the cylinders. The harmful ones include the inertia forces produced by the changing motion of reciprocating parts and the friction forces resulting from the relative motion of rubbing pairs.

The reciprocating and rotary motions of the crank mechanism components give rise to the inertia forces of the reciprocating masses and the centrifugal forces of the rotating masses. These forces are transferred to the engine body and thence to the frame of the tractor or automobile. The periodic variations of the inertia forces, both in magnitude and in direction, cause the engine and the vehicle as a whole to vibrate. These vibrations weaken the screwed joints of component parts and impose additional loads on the crankshaft bearings, thus accelerating their wear.

The balancing of an engine consists in creating such a system of forces acting in the engine under steady running conditions as will have its resultant forces and resultant moments of forces either constant in magnitude and direction or equal to zero. Counterbalancing the inertia forces is achieved by properly selecting the number of cylinders and the crankthrow arrangement and by using additional moving masses – counterweights. These methods are usually used conjointly. The crankthrows of four-cylinder engines are arranged at an angle of 180° to one another, so that the inertia forces generated by the two extreme pistons and their associated connecting rods moving in one and the same direction are almost fully counterbalanced by the inertia forces produced by the neighbouring pistons and connecting rods that move in the opposite direction (Fig. 23 *a*). The counterweights carried on the crankshaft webs balance the crank mechanism components associated with each cylinder.

In a two-cylinder tractor engine, the inertia forces due to the changing motion of reciprocating masses can be completely* counterbalanced by means of a special balancing mechanism (Fig. 23 *b*). The mechanism consists of two counterbalance weights *2* carried on the ends of balance shaft *3*. The shaft is supported in plain bearing bushes and is driven from the crankshaft through the intermediary of two idler gears *6*, so that it turns at the crankshaft speed but in the opposite direction. The flywheel and fan pulley carry counterweights *1* and *5*, respectively. The

* Actually, a small fraction of the forces remains unbalanced.



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Illustrating the balancing of engines

(a) four-cylinder engine;
(b) two-cylinder engine;
(c) engine balancing mechanism;
1 – flywheel counterweight;
2 – counterbalance weights;
3 – balance shaft;
4 – gear;
5 – fan pulley counterweight;
6 – intermediate (idler) gears;
7 – gears with counterweights;
8 – adjusting shims;
9 – crankshaft ring gear;
10 – housing

inertia forces F_{c1} acting along the axis of the first cylinder are equal but opposite to the inertia forces F_{c2} acting along the axis of the second cylinder, and so their sum is zero. But being equal in magnitude and opposite in direction, these forces produce a moment acting in the plane passing through the cylinder axes. This moment is counterbalanced by the resultant moment produced by counterbalance weights *2* and counterweights *1* and *5*.

Some medium-power four-cylinder tractor engines also use a balancing mechanism. It consists of two counterbalance weights *2* (Fig. 23 *c*) which turn in opposite directions at twice the crankshaft speed. The weights are cast integrally with the spindles pressed in gears *7*. The spindles rotate in cylindrical roller bearings installed in housing *10* of the balancing mechanism. The gears are driven from ring gear *9* mounted on the center part of the crankshaft near the third main bearing journal.

The rotation of the counterbalance weights gives rise to centrifugal forces F_c which are resolved into horizontal and vertical component forces. The horizontal forces acting in opposite directions cancel out, whilst the vertical ones combine, so that their resultant F_v counterbalances the resultant F_i of the inertia forces in all the four cylinders.

The balancing mechanism is assembled to the engine with the piston in the first cylinder at TDC, care being taken to mesh the gears so as to make the marks on their teeth and tooth spaces coincide. The gear backlash (within 0.2 to 0.35 mm) is adjusted by means of shims *8*.

4.5. Crank Mechanism Troubles

The normal operation of the crank mechanism is governed by the condition of its component parts. In service, the normal operation of the tractor or automobile may be disturbed as a result of some troubles. The most common among these are worn rubbing components, drop of compression in the cylinders, and oil and water leaks. Worn components are indicated by foreign engine noises (knocks), excessive oil consumption, smoky exhaust, and loss of engine power.

To locate the source of a noise due to excessively worn components, it is necessary to adjust the engine speed with the fuel pump or throttle lever so as to make the knocks most audible. It is recommended that the engine should be listened to with the aid of a mechanic's stethoscope or listening rod to carry the sound directly to the ear. To do this, the pickup end of the stethoscope or rod is moved around on various places on the engine to find where the noise is loudest. Engine noises vary in intensity and frequency, depending on their source. Thus, a sharp, metallic knock growing in intensity with increasing engine speed results from worn piston pins or their bushings. Dull, heavy metallic knocks audible in the lower part of the cylinder-block-and-crankcase unit, which vary in frequency as the engine speed is sharply changed, especially under load, are indicative of worn connecting rod or main bearings. A decrease in the oil pressure in the lubricating system is an additional indication of worn main bearings. Worn pistons or cylinder liners give rise to a clicking sound audible in the cylinder block at the beginning of the engine warmup period after starting.

Indications of worn piston rings are poor engine performance due to decreased compression in the cylinders and excessive crankcase oil consumption as a result of increased pumping action of the compression rings pumping oil into the combustion chamber.

A bluish tinge of the exhaust gas indicates that the engine is burning oil entering the combustion chambers because of worn cylinder liners, worn pistons, or worn or else stuck piston rings. Whitish exhaust smoke indicates water in the cylinders. The leakage of water into the cylinders from the water jacket can be eliminated by tightening up the nuts on the cylinder head studs. This is done with a torque indicating wrench in two or three operations in a definite sequence, working evenly from the center out to the extreme nuts at both ends of the head in a criss-cross fashion.

Bad condition of the rubber sealing rings between the cylinder liners and cylinder-block-and-crankcase unit may result in the jacket water leaking into the oil pan. The leakage of oil from the oil pan, bell housing, and timing case may be due to damaged or poorly fitting gaskets or, in some cases, worn crankshaft front and rear seals.

If an oil leak is detected, one should tighten up all the fasteners and, should this fail to rectify the situation, replace the damaged gaskets or worn sealing components. To avoid the ingress of dust into the engine interior, worn components are replaced at a shop, where the engine prior to disassembly is checked by an engine diagnostician, i.e., a diagnostic technician, on a test stand.

Review Questions

1. Name the structural components of the engine.
2. What is the purpose of partitions (bulkheads) in the cylinder-block-and-crankcase unit?
3. How are the cylinder liners sealed in the cylinder block?
4. What are the specific constructional features of the cylinder barrels and crankcase of an air-cooled engine?
5. What are the component parts of the crank mechanism?
6. What is the purpose of the breather?
7. What is the purpose of piston rings?
8. By what is the endwise movement of the crankshaft limited?
9. How is oil cleaned in the hollow interiors of the crankpins?
10. From what material are the crankshaft main bearings made?
11. What are the main indications of crank mechanism troubles?

Chapter 5
Valve Mechanism

5.1. Construction and Operation of the Valve Mechanism

Four-stroke engines use a valve mechanism (Fig. 24) for the timely admission into the cylinders of air (in diesel engines) or fuel-air mixture (in carburettor engines) and release from the cylinders of burnt gases. For this purpose, the valves at definite moments open and close the intake and exhaust ports in the cylinder head, through which the cylinders communicate with the intake and exhaust manifolds.

A distinction is made between side- and overhead-valve mechanisms. The automotive engines considered in this book use the overhead type of valve mechanism, with which the valves are mounted in the cylinder head.

The valve mechanism includes intake and exhaust valves with their associated springs, a camshaft, motion-transmitting components between the camshaft and the valves, and timing gears.

The valve mechanism operates as follows. The crankshaft imparts rotation to camshaft *14* via the timing gears. A cam lobe on the camshaft comes up under valve lifter (also known as the valve tappet or cam follower) *13* and moves it up. This pushes up on push-rod *12*. The push-rod moves up, pushing up on one end of rocker arm *7*. The rocker arm is mounted on shaft *8* so that it can rock back and forth. When one end of the rocker arm is pushed up by the push-rod, the other end pushes down on the end of the stem of valve *3*, pushing the valve down off its seat and compressing valve springs *6*, so that the valve opens.

When the cam lobe moves out from under the valve lifter, the valve lifter and push-rod move down and the valve, forced by the springs, sits in its seat, tightly closing its associated port.

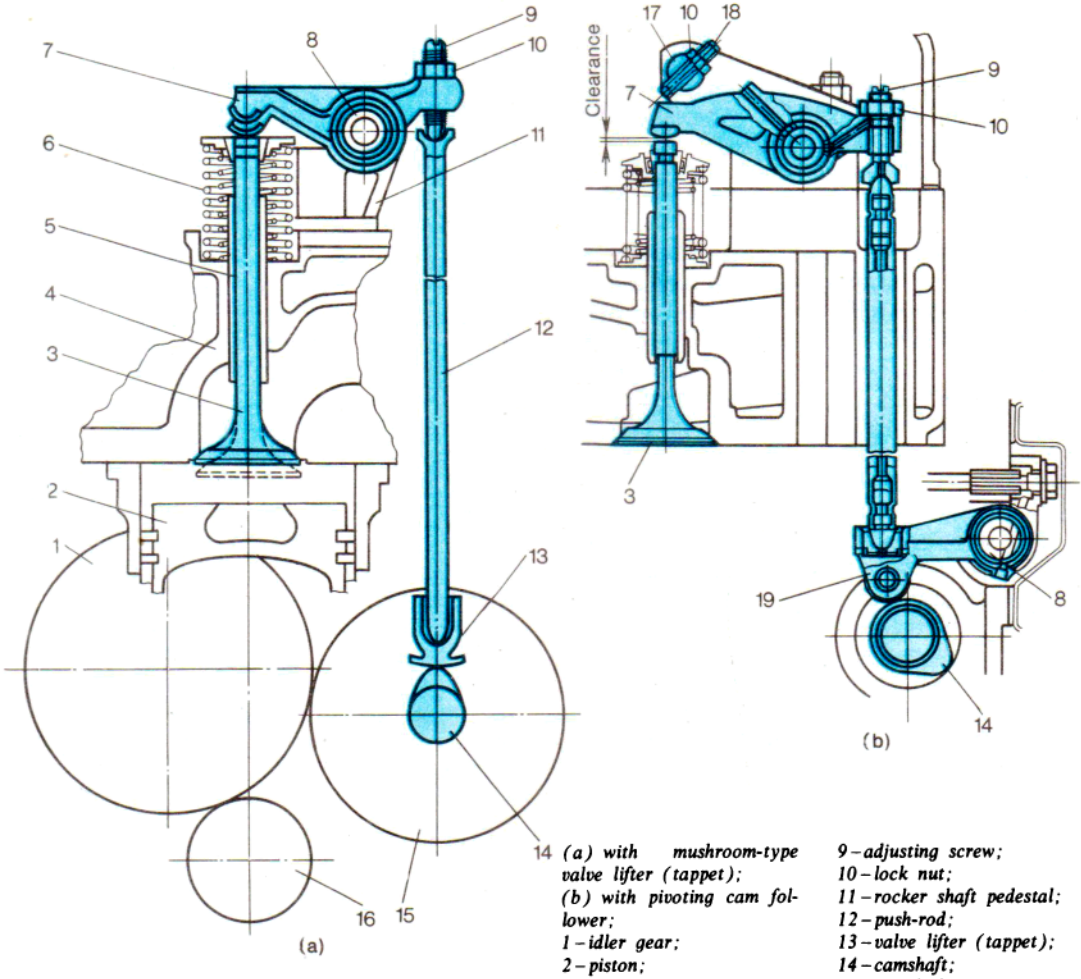
Earlier, when studying the engine cycle of operations, it was said that the valves open and close when the piston is either at TDC or at BDC. This is not exactly true. The opening and closing of the intake and exhaust valves are not, in actual practice, timed to coincide precisely with the beginning and ending of the intake and exhaust strokes. This departure from the basic operating cycle is made for two reasons. First, there are mechanical stress considerations imposing physical limitations on the rapidity with which the valves may be opened and closed. The initial opening and closing points of the valves must, therefore, take into account the time lapse before the valves are either fully opened or completely closed. Secondly, the incoming and outgoing flow of cylinder gases is subject to inertia effects. As a consequence, there is a reluctance of the gases both to commence and to cease flowing.

To accommodate these various effects, the valve timing of an engine provides for both the lead and lag of the intake and exhaust valve opening and closing. Thus, the intake valve is given a lead in opening so that it offers the least resistance to the incoming air or fuel-air mixture when the piston begins its intake stroke. It is also provided with a lag in closing to take advantage of the reluctance of the gases to cease flowing, as the piston ends the intake stroke. The maximum amount of air or fuel-air mixture is thus induced to enter the cylinder, on which largely depends the power developed by the engine. Similarly, the exhaust valve is given a lead in opening so that the burnt gases are already leaving the cylinder under their own pressure, as the piston begins its exhaust stroke. The engine, therefore, expends less energy in expelling the exhaust gases than would otherwise be the case. The exhaust valve is also provided with a lag in closing, here again to take advantage of the reluctance of the gases to cease flowing, as the piston ends its exhaust stroke. This serves the two-fold advantage of thoroughly scavenging the cylinder of the exhaust gases, while at the same time lowering the pressure in the cylinder to facilitate the flow of the incoming air or fuel-air mixture. The efficiency of an engine depends in a large measure upon the effectiveness of the scavenging and air or fuel-air mixture intake.

The periods between the opening and closing

points of the intake and exhaust valves, expressed in degrees of crankshaft rotation, are referred to in this country as the *valve timing phases*. These may be shown in the form of a table or a circular diagram, generally known as the valve timing diagram. Figure 25 shows the valve timing diagram of a modern tractor diesel engine. Here, giving the intake valve a lead in opening and a lag in closing made it possible to extend the intake phase from 180 to 242° of crankshaft rotation.

After the intake valve is closed, there occur in the cylinder air compression, fuel injection into the combustion chamber, and the power stroke of the piston. The release of the burnt gases from the cylinder, or the opening of the exhaust



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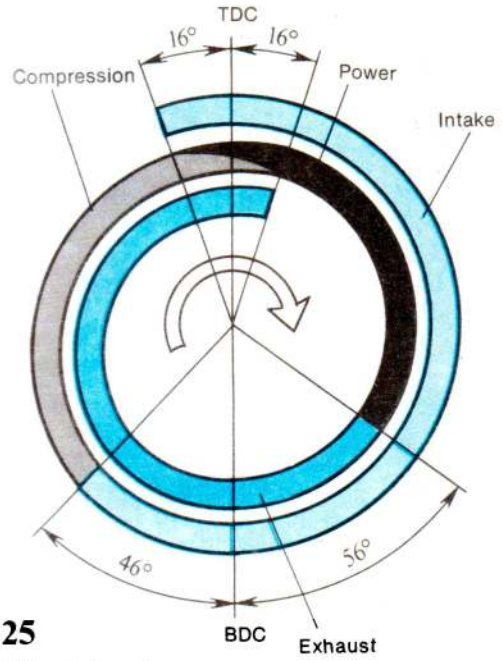
Schematic diagrams of valve mechanisms

(a) with mushroom-type valve lifter (tappet); (b) with pivoting cam follower;
1 – idler gear;
2 – piston;
3 – valve;
4 – cylinder head;
5 – valve guide;
6 – valve springs;
7 – rocker arm;
8 – rocker-arm shaft;
9 – adjusting screw;
10 – lock nut;
11 – rocker shaft pedestal;
12 – push-rod;
13 – valve lifter (tappet);
14 – camshaft;
15 – camshaft gear;
16 – crankshaft gear;
17 – compression release (decompressor) shaft;
18 – adjusting screw;
19 – pivoting cam follower



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Valve timing diagram

valve, starts at 56° of crankshaft rotation before the piston reaches BDC on its power stroke. So, by the moment the piston reaches BDC, some burnt gases have already left the cylinder, which decreases the counterpressure on the piston while it is expelling the gases out of the cylinder on its exhaust stroke. The exhaust valve is closed after the piston has passed BDC. The valve stays open during 252° of crankshaft rotation.

At the end of the exhaust stroke and the beginning of the intake stroke, both valves stay open for some period of time, corresponding to 32° of crankshaft rotation. Such a valve overlap facilitates the clearing of the cylinder of the burnt gases, as a result of its scavenging with fresh air.

The duration of the valve timing phases depends primarily on the crankshaft rotation frequency. The higher this frequency the greater are the crankshaft rotation angles that determine the valve timing phases.

The opening and closing points for the valves are determined by the shape of the lobes on the cams that operate the valves, the relationship between the gears on the crankshaft and the camshaft, and the clearances between the valve stems and the rocker arms.

5.2. Valve Mechanism Components

THE VALVES (Fig. 26) open and close the intake and exhaust ports in the cylinder head. They consist of a disc-shaped head and a stem. To impart the necessary mechanical strength to the valve and to improve heat removal and lower the resistance to the flow of gases, the valve stem is smoothly blended into the head portion to form a neck of fairly generous radius. The valve stem is ground, and its tip is hardened to reduce its wear under the action of the rocker arm. For tighter fit, each valve is ground in to its seat until a 1.5 to 2 mm wide seating surface, called the valve face, is obtained, which in most engines makes an angle of 45° with the plane of the valve head. The valves operate at high temperatures and are subject to the corrosive action of the cylinder gases. Therefore, the materials used for fabricating the valves must be heat-, corrosion-, and wear-resistant. As known from the science of materials, these requirements are satisfied by high-alloy grades of steel. The intake valves are made of chromium steel and the exhaust ones, of heat-resistant (silchrome) steel. To facilitate the admission of air or fuel-air mixture into the cylinder, the head diameter of the intake valves is made greater than that of the exhaust valves.

The valve stem is grooved near to its tip to receive a lock for holding the valve spring retainer and thus maintaining the valve spring pressure on the valve stem. Valve spring retainer lock *4* comprises a conical ring split into two halves. Some engines use valve lock cup *5* between the lock and the valve spring retainer, which holds the halves of the split lock clamped together and rests against valve spring retainer *3* by its narrow lower end, thus making it possible for the valve to turn relative to the retainer under the action of the rocker arm and also as a result of the valve spring vibrations. This is beneficial to the serviceability of the rubbing surfaces of the valve and its guide and

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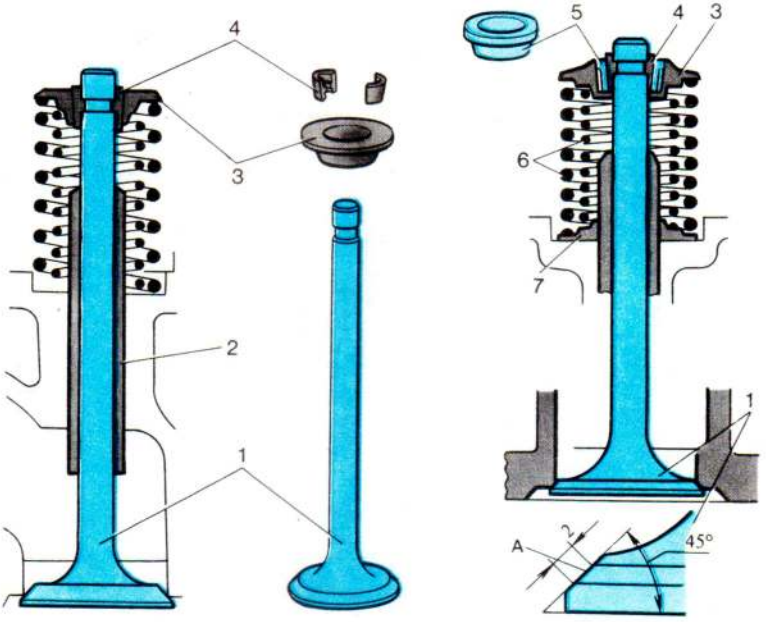
Valve mechanism of tractor engines

1 – valve;
2 – valve guide;
3 – valve spring retainer;
4 – valve spring retainer lock;
5 – valve lock cup;
6 – valve springs;
7 – valve spring seat;
A – valve face



seat and provides for their uniform wear.

The exhaust valves of some automobile engines are made to rotate positively by a special mechanism (Fig. 27) during engine operation. This mechanism, known as the valve rotator, consists of stationary housing *11* with five ramplike grooves along its circumference that contain five steel balls *12* loaded by return springs *13*. Freely placed on top of the balls is flexible washer (cone spring) *10* against which rests valve spring *3* through the intermediary of seating collar *9*.

As the valve is opened, spring *3* is compressed and its increasing load causes flexible washer *10* to flatten out and force balls *12* down their ramps against the resistance offered by their return springs. As the balls roll down, they turn through some angle the flexible washer, seating collar *9*, and valve spring *3* together with the valve. When the valve is closed, the valve spring load decreases, the flexible washer deflects to acquire its initial conical shape and, abutting against a shoulder in housing *11*, releases the balls which are then forced by their coil springs to return to their starting position.

In automobile engines, seating face 7 of the exhaust valves is hard-faced with a heat-resistant alloy. Valve stem *2* is made hollow and the cavity is filled 50 to 60% full with metallic sodium. The cavity is sealed off by stopper *1* welded to the valve head. The metallic sodium liquefies, but does not vaporize at valve operating temperatures and is capable of conducting heat much better than the valve material itself. Hence, the shaking of the liquid sodium due to the motion of the valve increases the heat transfer from the valve head to the stem and thence to the cooled region of valve guide *5*, thus reducing the valve head temperature.

The intake valves heat less during engine operation, since they are cooled by the incoming air or fuel-air mixture on the intake stroke. To lessen the leakage (pulling) of oil into the cylinder through the clearance between the intake valve stem and its guide, some engines use an umbrella-type oil deflector cup of oil-resistant rubber placed on the valve stem. This extends over the valve guide and is held fast under the valve spring seating collar.

Valve guide *5* supports the valve stem and

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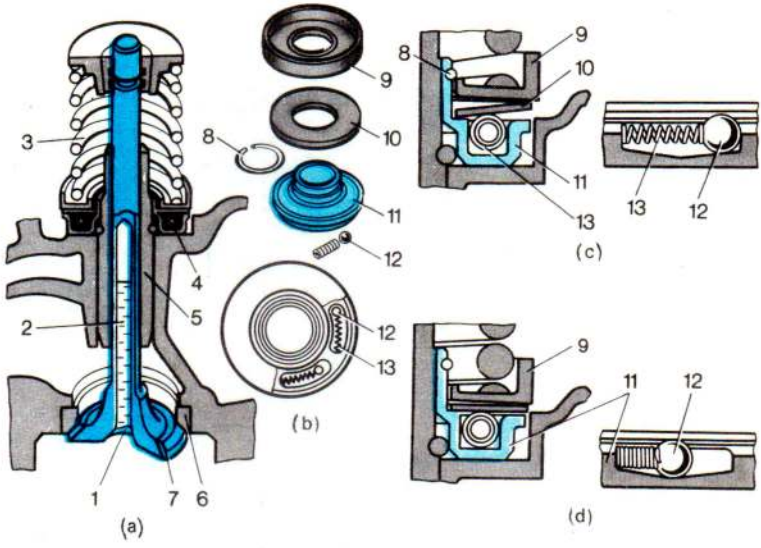
Valve mechanism of an automobile engine

(a) exhaust valve complete with valve rotator;
(b) valve rotator;
(c) valve rotator position with closed valve;
(d) valve rotator position with open valve;
1 – stopper;
2 – hollow valve stem;
3 – valve spring;
4 – valve rotator;
5 – valve guide;
6 – insert valve seat;
7 – valve face;
8 – snap ring;
9 – seating collar;
10 – flexible washer (cone spring);
11 – valve rotator housing;
12 – steel ball;
13 – return spring



guides its movement so that the valve face remains perfectly concentric with the valve seat and fits it without any skewing. Replaceable, or insert, valve guides are fabricated from cast iron or a cermet material and pressed in the cylinder head.

The intake and exhaust valve seats in many engines are formed by insert rings *6* of heat-resistant cast iron that are pressed in the cylinder head. This facilitates their renewal during repair.

Valve spring *3* provides the force necessary to close the valve and hold it tightly against its seat. Valve springs may have their coils spaced either evenly or variably. Variably spaced valve springs, also known as the progressive rate springs, lessen the tendency toward surging as a result of resonance effects. Where such springs are used, the close-wound end (with less coil spacing) must be installed toward the valve head.

Some engines use two springs on each valve, which reduces the size of the springs, improves their reliability, and makes their operating conditions less arduous.

THE MOTION-TRANSMITTING COMPONENTS of the valve mechanism serve to transmit motion from the camshaft to the valves. These include valve lifters, push-rods, rocker arms with adjusting screws, and rocker-arm shaft with pedestals and locating springs.

ROCKER ARM *5* (Fig. 28) is a bell-crank made of steel. At the middle of the rocker arm, there is a boss with a bore into which is pressed bushing *11*. A hardened curved pad is provided on the end of the rocker (on its longer arm) where it contacts the valve stem tip, while a threaded hole is machined in its other end to receive adjusting screw *2* used to set the valve clearance, i. e., the clearance between the rocker contact pad and the valve stem tip, so that the valve will be tightly pressed against its seat when hot. The rocker arm freely oscillates about shaft *7* supported by a series of pedestals, or brackets, *8* bolted to the top deck of the cylinder head. Locating compression springs *6* and spring clips prevent the rockers from moving sideways. The rocker-arm shaft is hollow, its cavity being used as a duct to supply oil to the rubbing surfaces of the rocker-arm bushings, adjusting screws, and push-rods. The ends of the hollow shaft are closed by plugs *3*.

PUSH-ROD *1* serves to transmit force from the valve lifter to the rocker arm. Push-rods may be

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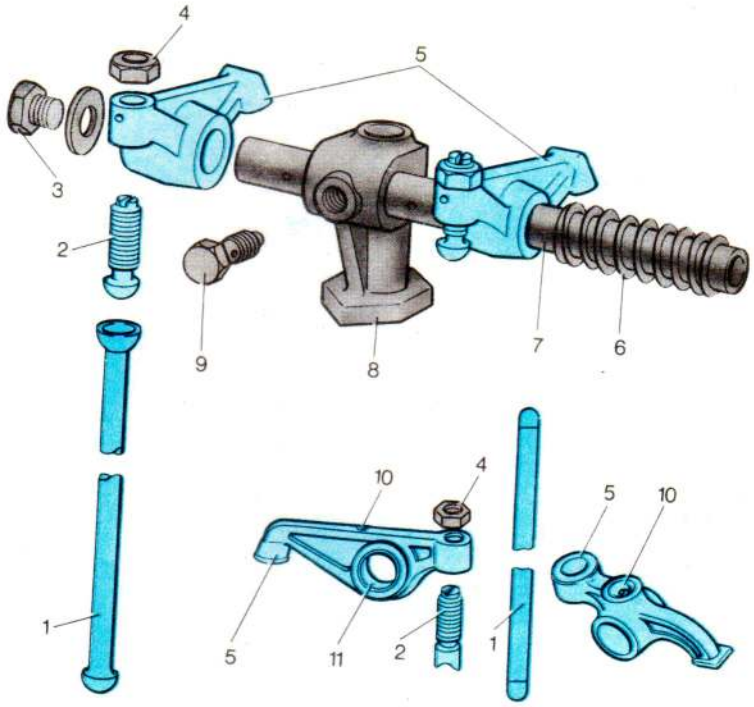
Rocker arms and push-rods

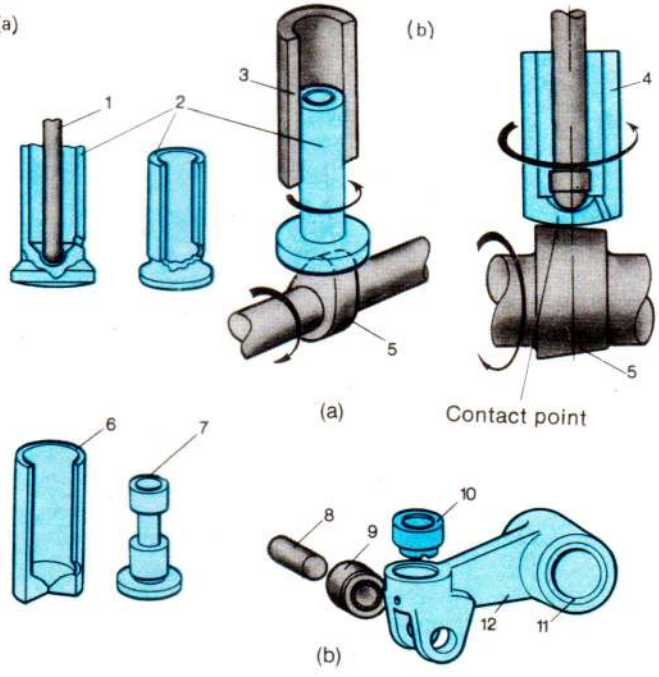
(a) socket-ended push-rod;
(b) ball-ended push-rod;
1 – push-rod;
2 – adjusting screw;
3 – plug;
4 – lock nut;
5 – rocker arm;
6 – locating spring;
7 – rocker-arm shaft;
8 – rocker-arm shaft pedestal (bracket);
9 – rocker-arm shaft bolt with oil hole;
10 – oil hole;
11 – rocker-arm bushing



29

Valve lifters (tappets)

(a) traditional tappets;
(b) pivoting roller-type cam follower;
1 – push-rod;
2 – mushroom-type tappet;
3 – tappet guide;
4 – spherical bottom barrel tappet;
5 – cams;
6 – flat-bottomed barrel tappet;
7 – recessed mushroom-type tappet;
8 – roller pin;
9 – roller;
10 – spherical seating;
11 – bushing;
12 – cam follower arm



fabricated from a solid or hollow steel bar. Push-rod ends are made in the form of either a ball or a socket and are thoroughly ground and heat treated. The lower end of the push-rod is ball-shaped. It engages the spherical socket in the valve lifter barrel. The upper end may be either ball- or socket-shaped and it mates with the spherical socket or the convex ball on the end of the adjusting screw in the rocker arm.

VALVE LIFTERS, OR TAPPETS (Fig. 29) are made of steel. The tappets, also known as cam followers, may be either of sliding or of pivoting type. The sliding type may have a plain cylindrical or a mushroom-like form. Plain cylindrical tappets (generally termed the barrel tappets) *4* and *6* and mushroom-type tappets *2* and *7* (Fig. 29 *a*) are provided with spherical seatings to effect engagement with the push-rods. The bottom contact faces of these tappets may be either flat or slightly convex. To ensure a uniform distribution of wear over the face, the tappets are induced to rotate as they reciprocate during engine operation. With flat-bottomed tappets, rotation is achieved by offsetting the tappet barrel axis relative to the cam axis, while in the case of spherical bottom tappets, this is effected by making use of cams that are slightly tapered across their width, as a result of which the contact point between the tappet face and the cam is offset relative to the tappet axis.

The pivoting roller-type cam followers (Fig. 29 *b*) take the form of a hinged lever arm. On one end of the follower arm, there is a boss with a bore into which is pressed bronze bushing *11* to receive a hollow shaft supported in the cylinder-block-and-crankcase unit. The other end of the cam follower carries roller *9* that rotates in a needle bearing and contacts the cam. Immediately above the roller, the follower is provided with insert spherical seating *10* that is press-fitted into a bore in the follower arm and engages the ball end of the push-rod.

CAMSHAFT *8* (Fig. 30) serves to open the engine valves positively and timely, in a definite sequence, and to control their closing against the return action of the valve springs. The shaft is made integral with its cams and bearing journals. Each cam controls a single valve, either intake or exhaust. The cam profile of the exhaust-valve cams is more obtuse than that of the intake-valve cams, hence the exhaust valves stay open for a longer period than the intake ones do. In some automobile engines, the camshaft is made integral with fuel pump eccentric *5* and oil pump drive gear *13*. The cams on steel camshafts are induction hardened.

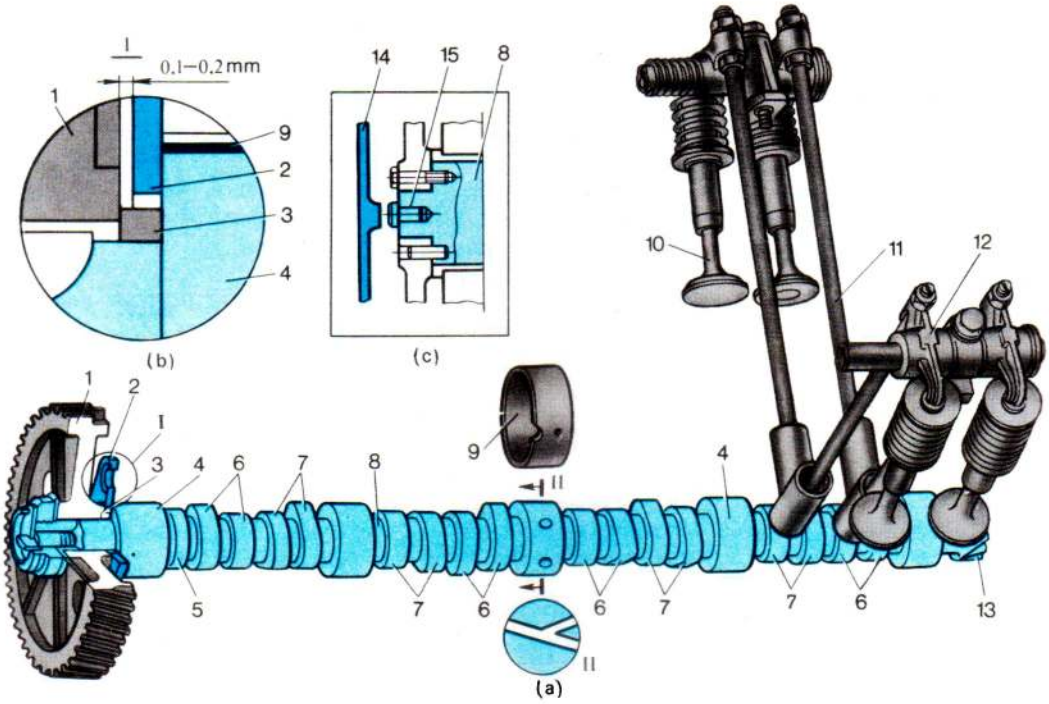
Camshaft journals *4* turn in sleeve bearings or bushings *9* pressed into machined bores in the cylinder block. The bushings may be made of steel, bronze, or a cermet material. Steel bushings are lined with an antifriction alloy.

To enable the camshaft to be inserted endwise through its bushings when it is installed in the cylinder block, the radius of its bearing journals is made slightly larger than the operating radius of its cams. The fitting of the camshaft bushings may be facilitated by making their outer diameters successively smaller in the direction of camshaft insertion, corresponding reductions in diameter being made to the bores that receive them.

The camshaft bearings are lubricated with oil supplied under pressure from the main gallery in the cylinder block. One of the camshaft bearing journals is provided with a cross-drilling to supply oil to a duct in the cylinder block that leads to the valve rockers. Oil enters the duct intermittently as the cross-drilling registers with the duct inlet.

In most engines, the front end of the camshaft carries timing gear *1*. The camshaft gear may be fabricated from steel, cast iron or fabric-base laminate. Sandwiched between the end faces of the timing gear boss and the camshaft front bearing journal is spacer ring *3* which is encircled by thrust plate *2* bolted to the front wall of the cylinder-block-and-crankcase unit to locate the camshaft axially. The ring is 0.1 to 0.2 mm thicker than the plate, and it is this difference that determines the camshaft end play.

The axial location of the camshaft in some engines is effected by a thrust button cast on timing cover *14* that acts against end thrust



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Valve operating mechanism of a V-type engine

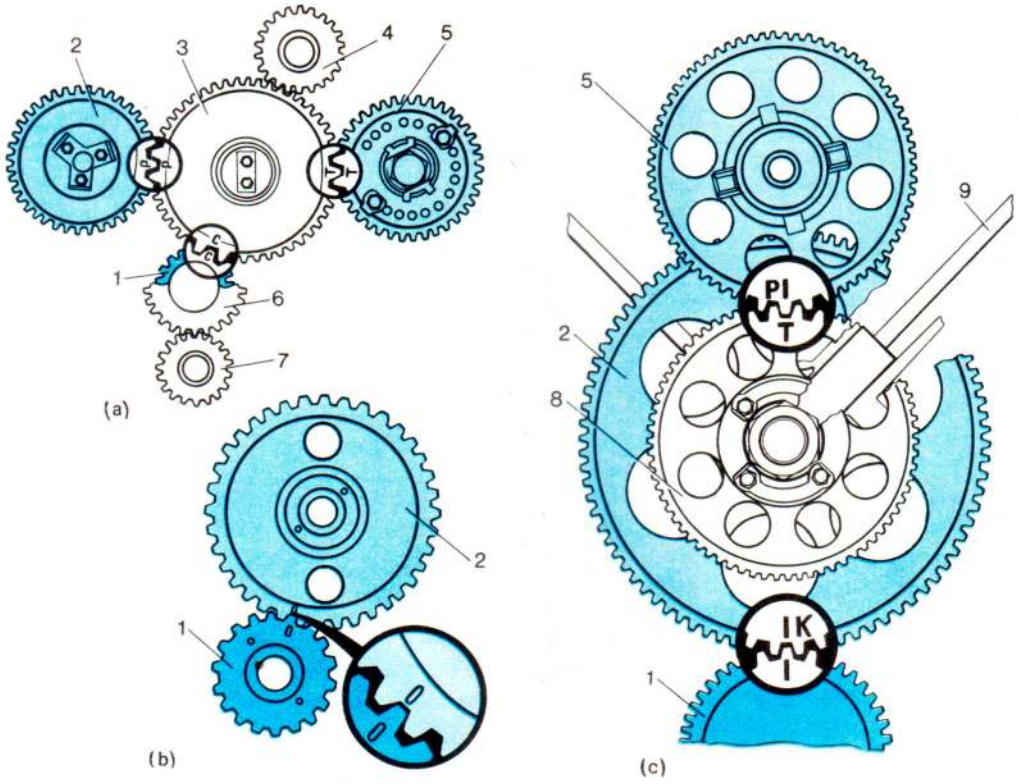
(a) construction;
(b) and (c) illustrating the means for limiting the axial play (end-float) of camshaft;
1 – camshaft gear;
2 – thrust plate;
3 – spacer ring;
4 – bearing journals;
5 – fuel pump eccentric;
6 – exhaust cams;
7 – intake cams;
8 – camshaft;
9 – camshaft bushing;
10 – intake valve;
11 – push-rod;
12 – rocker arm;
13 – oil pump and ignition distributor drive gear;
14 – timing cover;
15 – end thrust bearing

bearing *15* embodied in the nose of camshaft *8* (Fig. 30).

THE TIMING GEARS (Fig. 31) in most engines are housed in a special case fitted at the front end of the engine. These are necessary to transmit rotation from the crankshaft to the camshaft, fuel injection pump shaft, and to the oil pump, and other mechanisms. The gears are made of steel and use helical teeth to reduce noise.

The direction of rotation of the camshaft and fuel injection pump shaft in most tractor engines coincides with that of the crankshaft. Therefore, idler gear *3* (Fig. 31 *a*) is used between the gears carried on these shafts.

In four-stroke engines, each intake valve and each exhaust valve open once every complete cycle, and so, the camshaft must turn only once for every two revolutions of the crankshaft. Hence, the timing drive must provide for a 2 : 1 reduction ratio, i.e., the diameter (and the number of teeth) of crankshaft gear *1* must be half that of camshaft gear *2*. For the same reason, fuel injection pump drive gear *5* is twice as big as crankshaft gear *1*. To make the valve and fuel injection events correspond to definite positions of the piston in the cylinder, the above gears are meshed during assembly so that the timing marks on them coincide. Hydraulic pump drive gear *4* is set into rotation by the idler gear, while drive gear 7 of the oil pump is driven directly by the crankshaft gear. These gears are meshed without reference to any



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Meshing timing gears according to timing marks

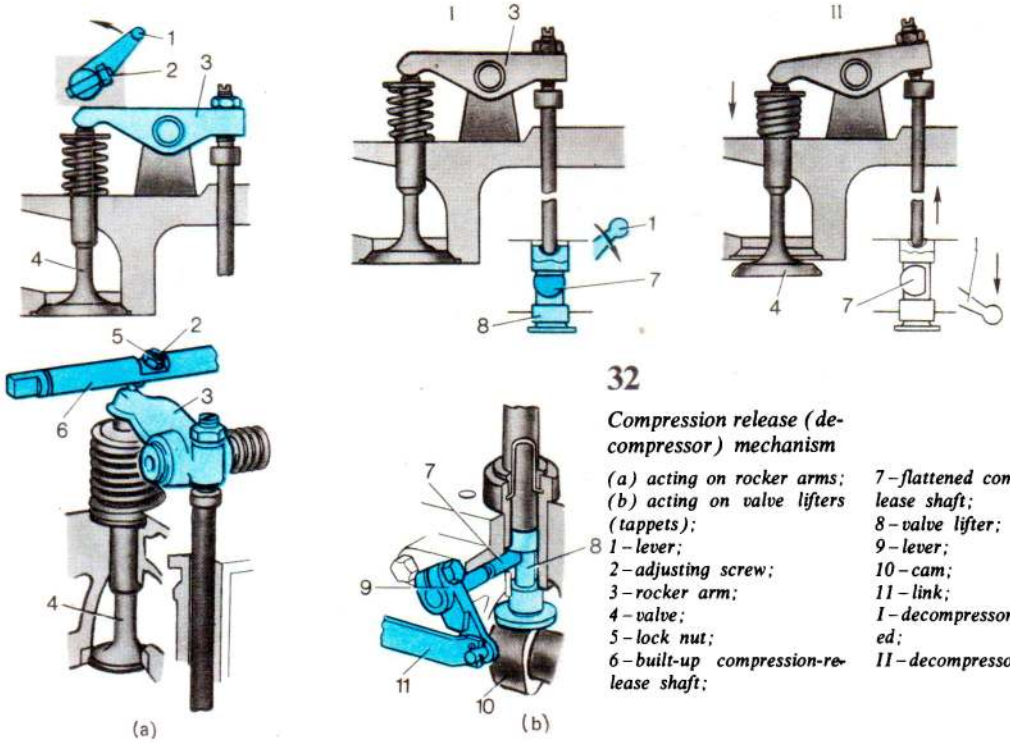
(a) with camshaft and fuel injection pump shaft revolving in the same direction as crankshaft;
(b) with crankshaft and camshaft revolving in opposite directions;
(c) with camshaft and fuel injection pump shaft revolving in opposite directions;
1 – crankshaft gear;
2 – camshaft gear;
3 – idler gear;
4 – hydraulic pump drive gear;
5 – fuel injection pump drive gear;
6 – oil pump drive gear;
7 – oil pump driven gear;
8 – fuel injection pump drive gear;
9 – push-rod

marks. If the camshaft and crankshaft rotate in opposite directions, no idler gear is used between them (Fig. 31 *b*). In some engines, the fuel injection pump shaft and the camshaft rotate in opposite directions (Fig. 31*c*).

5.3. Compression Release Mechanism (Decompressor)

To crank a diesel engine when adjusting its mechanisms or during starting, requires considerable efforts to overcome the resistance of the air being compressed in the cylinders. In order to reduce this resistance, many engines use a compression release mechanism or decompressor which, when actuated by hand, opens the intake valves or, in some engines, all the valves, so that air freely leaves the cylinders on the compression stroke, permitting the engine to be cranked more easily. The compression release mechanism is included in the starting system of the engine, but structurally it is part of its valve mechanism.

THE COMPRESSION RELEASE MECHANISM ACTING ON THE VALVE ROCKERS (Fig. 32*a*) consists of compression-release shaft *6* made up



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Compression release (decompressor) mechanism

(a) acting on rocker arms; (b) acting on valve lifters (tappets);
1 – lever;
2 – adjusting screw;
3 – rocker arm;
4 – valve;
5 – lock nut;
6 – built-up compression-release shaft;
7 – flattened compression-release shaft;
8 – valve lifter;
9 – lever;
10 – cam;
11 – link;
I – decompressor disengaged;
II – decompressor engaged

of two interconnected shafts and installed above the rockers and level *1* with a lock. Carried on the shaft opposite each valve are screws *2*. With the compression release mechanism disengaged, the tips of the screws point sideways and do not interfere with the normal operation of the valve mechanism. But as the decompression lever is shifted to engage the mechanism, shaft *6* turns and the tips of the screws depress the longer arms of valve rockers *3*, thus opening the valves.

The compression release shaft is locked in its engaged position by a spring catch. The distance the valve is depressed off its seat is adjusted by turning screw *2* in the shaft.

THE COMPRESSION RELEASE MECHANISM ACTING ON VALVE LIFTERS (Fig. 32*b*) comprises four decompression shafts *7* with flattened ends fitting in annular recesses machined in valve lifters *8*, lever *1*, and linkage components. With the flats on the ends of the shafts pointing upwards (running, or disengaged, position), the valve lifters are free to move, and the valve mechanism operates normally (Fig. 32, *I*). When the decompression lever is shifted into the warmup (engaged) position, the shafts turn so that their flats point sideways (Fig. 32, *II*) and the cylindrical portions of their ends lift the valve lifters. As a result, intake valves *4* in all cylinders are depressed off their seats and compression there vanishes.

As distinct from the decompressor acting on the valve rockers, the mechanism acting on the valve lifters has no provision for adjusting the distance the valves are depressed off their seats.

When starting the engine, the decompressor is first engaged and the engine is cranked with the aid of the starting device until the crankshaft is rotating stably at 250 to 300 rpm and then the decompressor is disengaged and the fuel feed is turned on. The engine then catches and starts running.

5.4. Valve Mechanism Troubles

In the course of operation, the rubbing surfaces of the valve mechanism components suffer wear, with the result that the clearances in the movable joints of the mechanism grow larger with time. Moreover, the contact between the valve faces and seats, or the valve seating, gradually deteriorates as a result of the action of hot combustion gases and impact loads and also because of carbon being deposited on the valves and their seats.

Basic valve mechanism defects include worn and burnt valve faces and seats, worn valve stems and guides, worn rocker-arm contact pads and adjusting screws, worn push-rod ends and tappets, worn cams and camshaft bearing journals and bushings, worn timing gear teeth, and weakened valve springs. These defects are evidenced by characteristic knocking noises and result in poor engine performance.

To ensure that the valve mechanism will operate normally, it is necessary to carry out certain tuneup procedures periodically and in strict compliance with the pertinent service regulations. These procedures include the checking and tightening of fasteners holding the cylinder head, rocker-arm shaft pedestals, and other components, the checking and adjusting of the valve clearances and the compression release mechanism.

The engine will operate normally only if the valves open and close in conformity with the valve timing diagram and, when in the closed position, tightly close their ports in the cylinder head, and it is incorrect valve clearances that may disturb the timely opening and closing of the valves.

Standard valve clearances for automotive engines are listed in Appendix 3. Too small or too large a valve clearance reduces the engine power and increases specific fuel consumption. With the valve clearance too small, the valve poorly fits its seat when hot, this causing premature burning of the valve face and seat. Where the valve clearance is too large, the valve stays open for a shorter period than required (see the valve timing diagram of Fig. 25) and starts knocking, valve knocking being attended by intensive wear of the valve rocker contact pad and the valve stem tip.

The valve adjustment sequence for the engines considered in this text is as follows. Clean and remove the cylinder head cover. Tighten the rocker-arm shaft pedestal fasteners and engage the compression release mechanism. Crank the engine over to position the piston in No. 1 cylinder at TDC, or slightly before TDC; at the end of its compression stroke, disengage the compression release mechanism, and check the valve clearance with a suitable feeler gauge slipped between the rocker arm and valve stem. Should the clearance prove to be wrong, adjust it using a wrench and a screwdriver. To do this, loosen locknut *10* (see Fig. 24*b*) and turn adjusting screw *9* until the feeler gauge has a slight drag when pushed and pulled between the contact surfaces of the valve rocker and stem. Then tighten the locknut and recheck the clearance.

If the engine uses an adjustable compression release mechanism adjust the compression release in No. 1 cylinder simultaneously with the valves. For this purpose, engage the mechanism, i.e., position compression-release shaft *17* so as to make the axis of adjusting screw *18* assume a vertical position, loosen the locknut securing the screw, and turn the screw counterclockwise until it looses contact with the valve rocker. Then turn the screw back until the contact pad on the valve rocker just touches the valve stem. Add another turn to the screw and tighten the locknut.

Successively turning the crankshaft half a revolution, adjust the valve clearance and compression release in all the other cylinders in their firing order. In multicylinder engines with more than four cylinders, the valve clearance can be adjusted in several cylinders at a time.

The valve clearance and compression release adjustments finished, install the cylinder head cover in place. Then start the engine and make sure that there are no oil leaks from under the cover.

Review Questions

1. What is the purpose of the valve mechanism?
2. What is the purpose of the compression release mechanism?
3. Why is a clearance needed between the valve stems and rockers?
4. Why is the crankshaft gear diameter half the camshaft gear diameter?
5. What is the material the valves are made of and what is the difference between the valves?
6. Why are the timing gears meshed according to timing marks?
7. What types of compression release mechanisms do you know?
8. List the procedures carried out when servicing the valve mechanism.
9. How are the valves adjusted?
10. What is the compression release adjustment sequence?

Chapter 6
The Cooling System

6.1. Cooling System Classification

The temperature of gases in the cylinders of a running engine averages around 1000°C. During engine operation, the gases heat the walls of the cylinders, pistons, and cylinder head. If the engine had not been cooled properly, the film of lubricating oil between the rubbing components of the engine would have been burnt off, resulting in undue wearing of the components, possible seizure of the pistons because of their excessive expansion, and other troubles.

An excessive heat removal from the engine (engine overcooling) reduces the engine power and increases the consumption of fuel, because of poor air-fuel mixing conditions and increased friction losses due to poor lubricating properties of oil at low temperatures. Excessively low operating temperatures cause incomplete burning of the heavier fuel fractions, resulting in heavy carbon deposits accumulating on the combustion chamber walls, pistons, and valve heads, with ensuring seizure of the piston rings and valves.

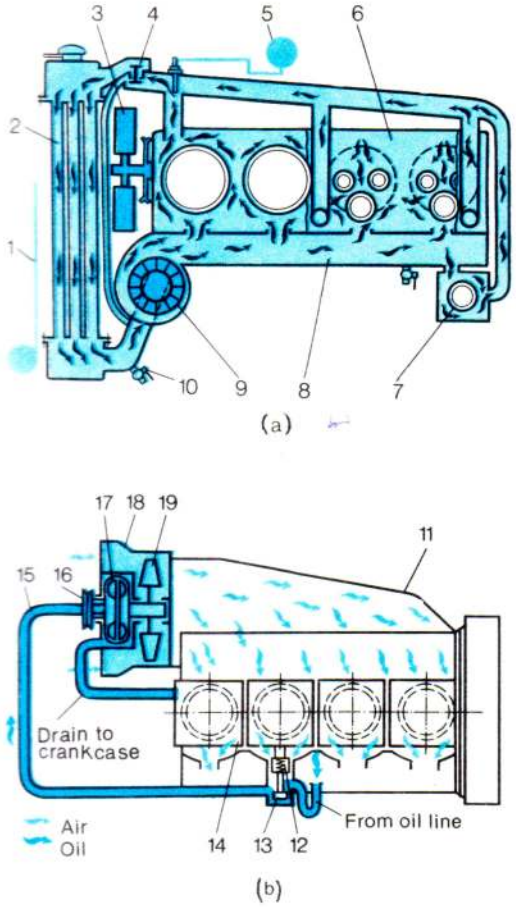
Thus, the overcooling of the engine is as undesirable as its overheating. For a water-cooled engine to operate normally, the temperature of the cooling water must be in the range 80 to 95°C.

The cooling system serves to remove heat from the hot engine components and maintain normal temperature conditions of the running engine. The withdrawal of the excess heat in internal combustion engines is effected through their forced cooling by some liquid (liquid cooling) or the ambient air (air cooling).

ENGINES WITH A LIQUID COOLING SYSTEM (Fig. 33*a*) are the more common. The cooling medium, or coolant, in them is either water or some low-freezing liquid, called antifreeze. The system includes water jacket *6* for cooling the cylinder block and head, radiator *2*, water pump *9*, and fan *3*, and also auxiliaries: coolant distribution manifold *8*, thermostat *4*, connecting hoses, drain cocks, and coolant temperature gauge (thermometer) *5*.

In diesel engines using an auxiliary internal combustion engine for starting purposes, the starting engine, as it runs prior to cranking the main engine, is cooled by natural convection. The cooling water flows, as a result of temperature difference, from the cylinder jacket to the cylinder head jacket of the starting engine and thence to the cylinder head jacket of the main engine, where it gives off its heat to the cylinder head, and then flows back to the cylinder jacket of the starting engine. The natural circulation of the water by convection is known as thermo-siphon cooling.

When the main engine is running, the cooling water is forced to circulate through the cooling system by centrifugal water pump *9*. The pump draws water from the radiator lower tank, termed the collector tank, and forces it under pressure into cylinder block jacket *6* where it cools the walls of the cylinder. The water then passes upwards through holes and ducts into the cylinder head jacket. The ducts direct vigorous flows of water around the exhaust



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Schematic diagrams of cooling systems

(a) liquid cooling;
(b) air cooling;
1 – radiator shutter;
2 – radiator;
3 – fan;
4 – thermostat;
5 – temperature gauge;
6 – main engine water jacket;
7 – starting engine water jacket;
8 – coolant distribution manifold;
9 – water pump;
10 – radiator drain cock;
11 – air ducting (shroud);
12 – oil-feed regulator;
13 – piston valve;
14 – cylinder head;
15 – oil pipe;
16 – rotary blower drive pulley;
17 – fluid coupling;
18 – inlet vane device;
19 – blower rotor

guides and seats that are subjected to the most severe heating and also around the brass injector tubes, or sleeves, to protect the fuel-injection nozzles against overheating and prevent their spray holes being clogged with carbon. While the engine is cold, the water leaving the cylinder head is directed by the thermostat to the inlet side of the water pump, so that it flows by-passing the radiator (along the minor coolant circuit), but after the engine has warmed up, the thermostat directs the water to the upper, or header, tank of the radiator (along the major coolant circuit). As the water flows through the numerous tubes between the header and collector tanks of radiator *2*, it is cooled by the air that is induced to flow between the tubes by cooling fan *3*. The water leaving the collector tank is again forced by the water pump into the engine jacket.

Thanks to the relatively high rate of coolant flow maintained in the cooling system, the difference in coolant temperature between the outlet and inlet of the engine jacket is not very high (4 to 7°C), which is beneficial for a more uniform cooling of the engine.

Modern engines use a pressurized (sealed) cooling system in which the radiator is hermetically sealed and communicates with the atmosphere only if the pressure in the system goes too high or falls too low. To this end, the radiator filler neck is closed by what is known as the radiator pressure cap which is essentially a filler cap incorporating a pressure relief (control) valve and a vacuum (recuperation) valve. Pressuring the cooling system allows the coolant to circulate at a higher temperature without boiling, which improves the engine operating conditions. A further advantage of using a sealed cooling system is that the coolant losses through evaporation and surging are minimized.

IN ENGINES WITH AN AIR COOLING SYSTEM (Fig. 33*b*), the removal of heat from the high-temperature surfaces of the engine is effected by inducing air to flow around the cylinders and their heads. The forced circulation of air around the engine is provided by a rotary blower consisting of rotor (impeller) *19* with a large number of blades, or vanes, and

stationary inlet vane device *18*. Revolving with a high speed, the rotor forces the cooling air under sheet-metal air ducting, or shroud, *11* that almost entirely encloses the engine.

The air cooling system is provided with a means for controlling automatically the engine cooling conditions, in accordance with engine cooling requirements, by varying the speed of the blower rotor. This takes the form of fluid coupling *17* installed between drive pulley *16* and the rotor of the blower, the amount of oil filling the coupling being changed by oil-feed regulator *12* mounted in the cylinder head. The coupling comprises two vaned members: the driving member, called the pump, or impeller, and the driven member – the turbine, or runner. The latter is rigidly attached to rotor *19* and has no direct mechanical connection with the pump which is attached to the drive pulley.

The automatic device operates as follows. While the engine is being warmed up and the cylinder head temperature is too low, piston valve *13* is closed and does not let oil flow from the lubricating system into the fluid coupling. As a result, there is no oil in the coupling, and the turbine with the blower rotor does not rotate. The engine warms up rapidly, and as the required warm-up temperature is reached, the sensing unit of regulator *12* moves valve *13* to let oil enter the fluid coupling. The oil flowing into the coupling is entrained by the vanes of the pump and is thrown into the turbine with great force. It hits the turbine vanes at an angle and in this way applies pressure to one side of the vanes. The push against the vanes forces the turbine to turn together with the blower rotor.

The housing of the fluid coupling is provided with holes (1.5 mm in diameter) through which oil continuously drains into the engine crankcase.

The higher the temperature of the engine, the greater the amount of oil filling the fluid coupling and the higher the speed of the blower rotor. As the engine temperature goes down, the valve of the oil-feed regulator is moved to restrict the flow of oil into the coupling, and the blower slows down.

6.2. Liquid Cooling System Components

RADIATOR. The purpose of the radiator is to cool the water that enters it from the water jacket of the engine. The radiator of the engine cooling system (Fig. 34) consists of a header (upper) and a collector (lower) tanks, a core, and mounting components. For better conduction of heat, the tanks and the core, which is soldered to the tanks, are made of brass.

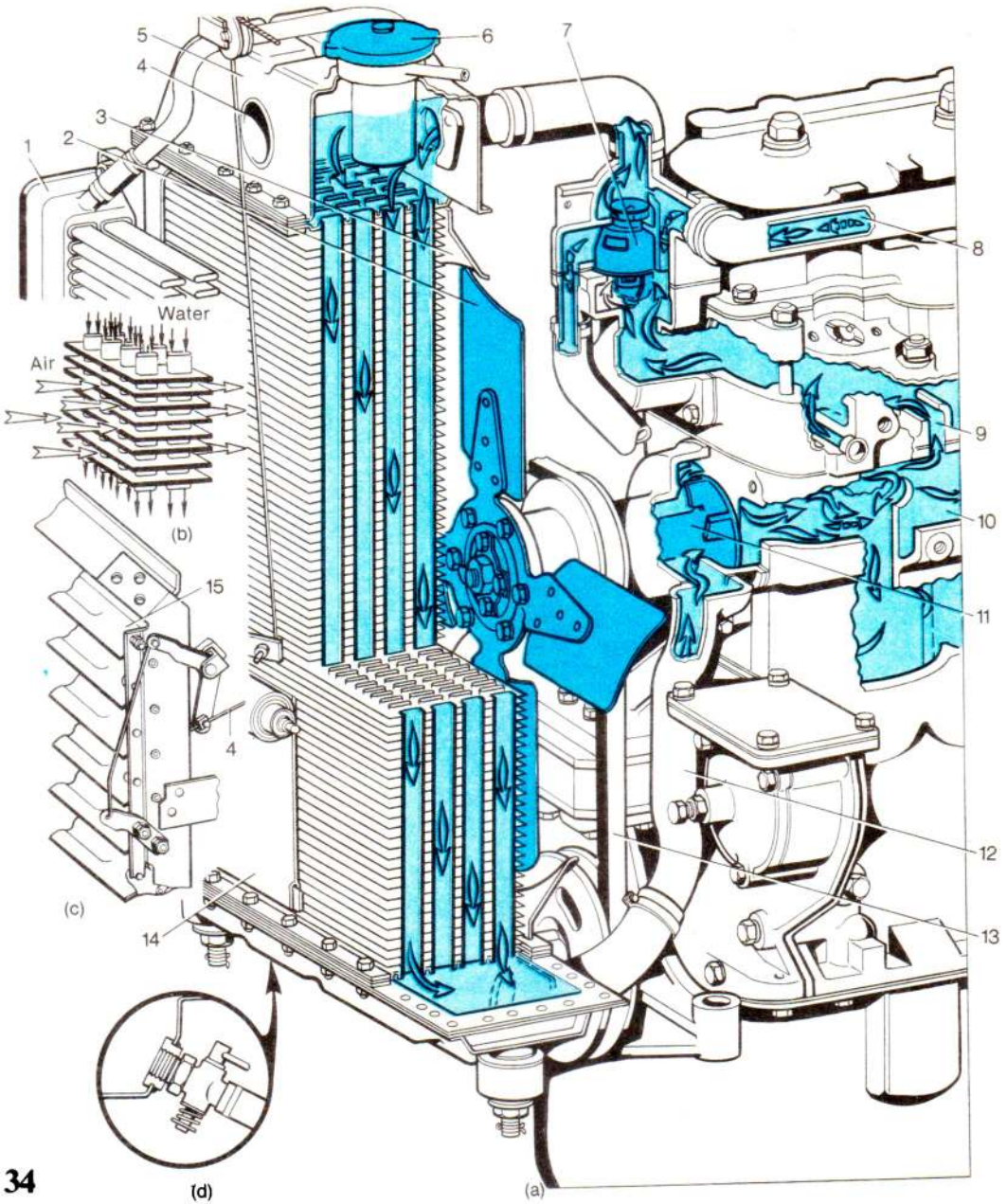
The radiator core, or matrix, comprises a series of thin horizontal fins through which pass numerous vertical tubes of flattened oval section, the fins and the tubes being solder bonded together. The heated water entering the radiator is dissipated into a large number of fine streams through its core. With such a core structure, the water is cooled more intensively, owing to the increased contact surface area between the water and the tube walls.

The header and collector tanks are connected to the engine cooling jacket by means of suitable pipe connections and hoses. The collector tank is equipped with a drain cock to drain water from the radiator. Screwed in the cylinder block in its lower part is a similar cock to enable the engine jacket to be drained.

The cooling system is filled with water through a filler neck provided on the header tank. The neck is closed by cap *6*.

In the liquid cooling system, provision is made for a dual control of the engine temperature conditions: by the radiator blind (or shutter) and the thermostat.

Radiator blind *14* is a piece of canvass whose one end is wound around a drum with a winding gear inside and the other end is held fast at the bottom of the radiator. The blind can be lifted and lowered by means of a control cable operated from the driver's cab. Some cooling systems use a radiator shutter instead of the blind. The shutter consists of a series of blades, or plates, *15* hinged to an operating bar which is linked with a control handle in the driver's cab by means of a system of levers and a control cable. The shutter blades may be arranged either vertically or horizontally. Both



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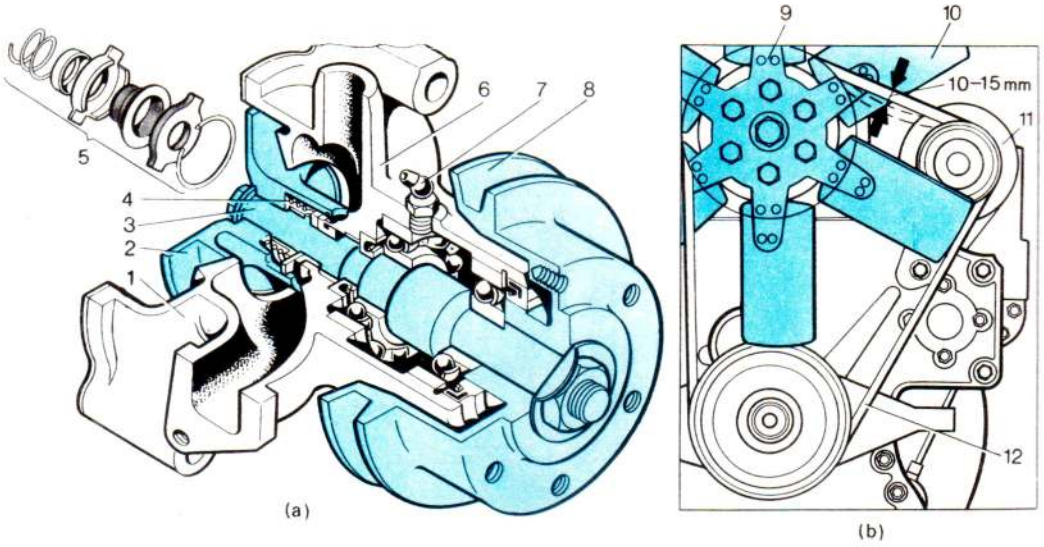
Engine cooling system

(a) construction;
(b) illustrating the flow of water and air through the radiator;
(c) radiator shutter;
(d) radiator drain cock;
1 – oil cooler;
2 – fan;
3 – fan shroud (cowl);
4 – radiator blind (or shutter) control cable;
5 – radiator;
6 – radiator filler cap;
7 – thermostat;
8 – starting engine water outlet pipe;
9 – water passage;
10 – water distribution manifold;
11 – water pump;
12 – water pump pipe;
13 – fan belt;
14 – radiator blind;
15 – radiator shutter plate



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Water pump and cooling fan

(a) construction;
(b) drive;
1 – pump body;
2 – impeller;
3 – shaft;
4 – spring;
5 – seal assembly;
6 – top pipe;
7 – lubricator;
8 – pulley;
9 – fan blade carrier;
10 – fan blade;
11 – generator;
12 – belt

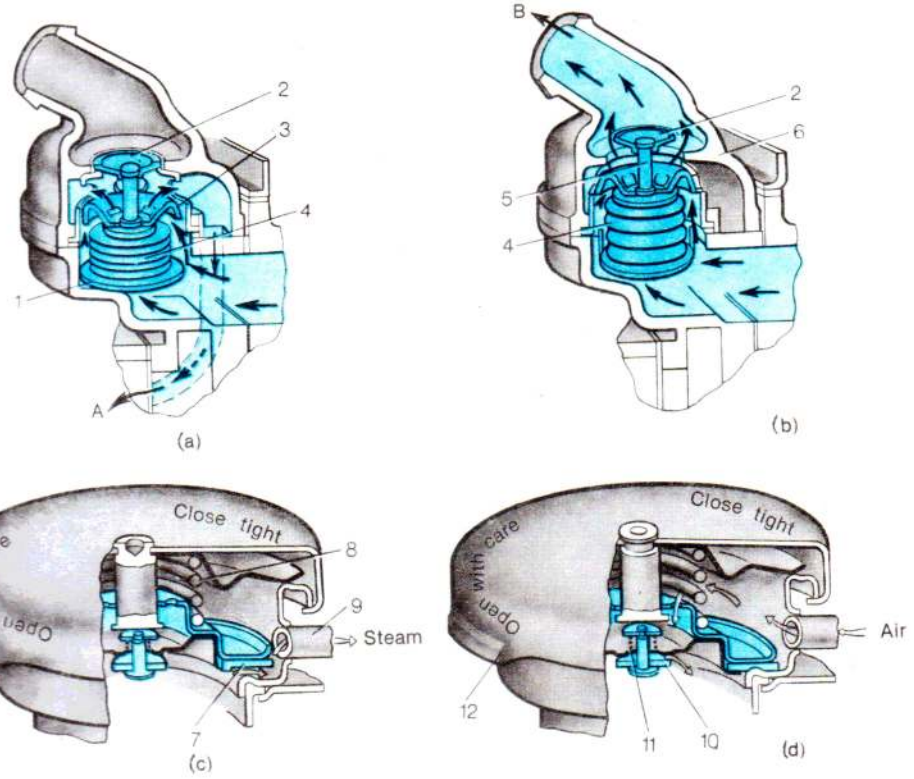
the radiator blind and shutter systems help to maintain the engine temperature by closing off the airflow to the radiator.

COOLING FAN AND WATER PUMP (Fig. 35). The fan has four or six blades *10* riveted to carrier *9*. The carrier is bolted to pulley *8* that is driven by the crankshaft through a belt drive. The pulley is rigidly fixed by a key and nut on water pump shaft *3* which is free to rotate in two ball bearings installed in pump body *1*. Rigidly fixed on the other end of the shaft is pump impeller *2*. This is a disc having a series of curved vanes evenly spaced along its circumference. When the impeller spins, the water between the vanes is thrown outward and is forced into the engine cooling jacket.

Where the pump shaft enters the pumping chamber, there is a seal to prevent water leakage and exclude air. The seal is installed in the cylindrical impeller hub and is locked there by a circlip. It includes a sealing ring of fabric-base laminate and a rubber cup which is pressed against a thrust bush by a spring. The water that has found its way past the seal during pump operation is drained through a hole provided in the pump body.

The water pump is bolted to the front wall of the cylinder block, a gasket of rubberized asbestos fabric being used between the pump body and the block. The pump body is provided with two pipe connections – a side connection to connect the pumping chamber to the bottom radiator connection and top connection *6* to connect the chamber to the thermostat housing.

THERMOSTAT (Fig. 36*a* and *b*) automatically controls the temperature of the cooling water to accelerate the warm-up of the engine after starting. It is made of brass. Soldered to the bottom of thermostat frame *1* is bellows *4* carrying by-pass (secondary) valve *3* and hollow thrust rod *5* with main (primary) valve *2*. The bellows of the thermostat is made in the form of a sealed cylindrical container with



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(a) and (b) Thermostat and (c) and (d) radiator pressure cap

a) main (primary) valve closed;
b) main valve open;
c) pressure relief (control) valve open;
d) vacuum (recuperation) valve open;
A – water flow to pump;
B – water flow to radiator;
1 – frame;
2 – main valve;
3 – by-pass (secondary) valve;
4 – bellows;
5 – thrust rod;
6 – thermostat housing;
7 – pressure relief valve;
8 – pressure valve return spring;
9 – steam vent (overflow) pipe;
10 – vacuum (recuperation) valve;
11 – vacuum valve return spring;
12 – radiator filler cap

corrugated walls of thin sheet brass and is partially filled with a low-boiling liquid – a mixture of water and ethyl alcohol.

While the water temperature remains below 70°C, the vapour pressure in the thermostat bellows is low and it stays compressed under the spring action of its resilient walls; the main valve is fully closed and the by-pass one is fully open. The cooling water circulates along the minor coolant circuit, i.e., around the engine only, and thus by-passes the radiator. The thermostat valves remain in their initial position until the water temperature rises in excess of 70°C. At this point the thermostat bellows begins to extend under the pressure exerted by the evaporating liquid it is filled with, moving both valves in the direction of water flow. The water starts flowing to the radiator through the partially open main valve. As the water temperature rises further, the positions of the thermostat valves are gradually reversed until finally the main valve is fully opened and the by-pass valve is fully closed at somewhere above 85°C, so that the flow of water to the water pump through the by-pass is closed off and the normal water circulation

through both the engine and radiator is restored.

Some engines use single- and double-valve thermostats operating on the hydrostatic principle. With these so-called wax-pellet thermostats, the control valve is energized by an element charged with a solid wax substance – ceresin (paraffin wax) – having a high coefficient of thermal expansion. The element consists of a cylindrical metal body containing the wax substance which surrounds a rubber insert, this in turn embracing a central operating thrust rod. When the coolant temperature reaches 70 to 83°C, the wax melts, expands, and compresses the rubber insert, but since this rubber is constrained to act like an incompressible hydraulic liquid, it displaces the thrust rod. The control valve is thus opened against its return spring and the coolant begins to circulate through the radiator. When the coolant temperature drops down, the wax solidifies and contracts. The control valve is then closed by its return spring and the coolant circulates through the engine only.

The cooling systems of some engines have no thermostat at all.

RADIATOR PRESSURE CAP (Fig. 36*c* and *d*) serves the purpose of maintaining the cooling-system pressure at a definite level during engine operation and equalizing it with atmospheric pressure when the engine is cooled off. This is essentially radiator filler cap *12* incorporating pressure relief (control) valve *7* which tightly closes the radiator filler neck under the action of spring *8*. If the water temperature in the radiator rises up to 105°C, the steam pressure in the radiator overcomes the spring loading on the valve, the valve is lifted off its seating in the radiator filler neck and vents the excess steam to the atmosphere.

The pressure relief valve is in turn equipped with a similar acting and concentric vacuum (recuperation) valve *10* which is arranged to open in the reverse direction against the relatively light loading of return spring *11*. When the engine cools off, the water in the cooling system contracts and the steam in the radiator header tank condenses. This produces a depression in the cooling system. Now the vacuum valve opens to admit air to the radiator. When the pressure in the radiator becomes equal to atmospheric pressure, return spring *11* closes the valve. The vacuum valve allows the cooling system to be fully drained without removing the cap and protects the radiator tubes and tanks against collapse when the engine cools off.

The coolant temperature is monitored with the aid of indicator lights and remote-indicating temperature gauges. The lights and gauges are mounted on the instrument panel of the tractor or automobile, while their sending units are installed either in the engine cylinder head or in the radiator header tank.

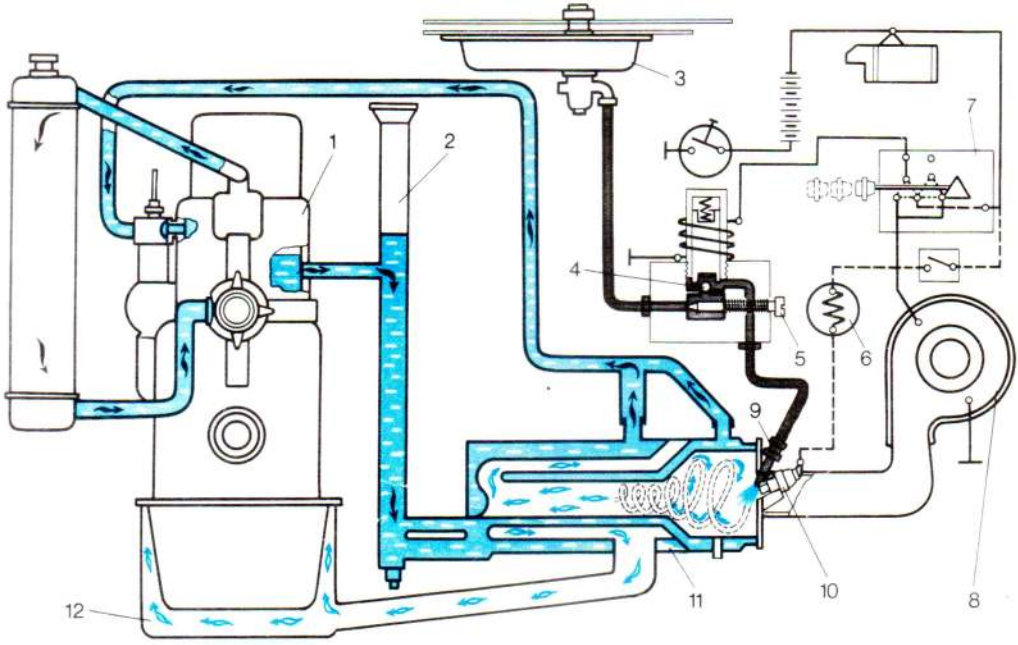
PRESTART HEATER. Since many water-cooled engines will not start easily at ambient temperatures below 5°C, various devices are available to facilitate ignition under these adverse conditions. The most effective among them is the gasoline-burning combined cylinder-block coolant and engine-oil heater referred to in this country as the prestart heater.

The heater (Fig. 37) consists of boiler *11*, oil pan shroud *12*, fuel tank *3*, electric blower *8*, solenoid-operated fuel valve *4*, connections, and a control unit.

The heater control unit is a metal box accommodating glow-plug pilot *6*, and on-off switch, and selector switch *7*. The latter is used to control the operation of the blower and fuel valve.

Fuel (low-grade gasoline) is fed to the fire box of the heater boiler from tank *3* by gravity. The amount of fuel entering the fire box is metered by adjusting needle *5* of fuel valve *4*. Air is supplied into the fire box by blower *8*. The air-fuel mixture formed in the fire box is ignited by glow plug *10*. The operation of the plug is monitored by watching the glow of pilot *6*. The heater boiler is filled with water or an antifreeze solution through filler *2*.

The heater is put into operation in a definite sequence, as specified in the pertinent tractor or automobile operating instructions. The flame resulting from the combustion of fuel in the fire box heats the boiler which is connected to the engine water jacket. At the same time, the hot



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Prestart heater

1 – engine;
2 – heater filler;
3 – fuel tank;
4 – solenoid-operated fuel valve;
5 – adjusting needle;
6 – glow-plug pilot;
7 – selector switch;
8 – electric blower;
9 – fuel pipe union;
10 – glow plug;
11 – heater boiler;
12 – oil pan shroud

combustion gases that are directed to shroud *12* warm up the oil contained in the engine crankcase. The water in the engine cooling system is thus heated to a temperature of 60 to 70°C, the temperature of the crankcase oil reaching 40 to 50°C. The prestart heater ensures that the engine will surely start within 20 minutes.

With the ambient temperature below – 15°C, it is recommended that the system should be filled with hot, rather than cold, water or antifreeze solution.

When using the prestart heating system, bear in mind that operating the heater with empty boiler for more than 1.5 min is prohibited. An incomplete filling of the boiler with water causes its overheating and eventual damage. Never re-start a hot heater without using its blower first to scavenge the fire box. To avoid the danger of carbon monoxide poisoning, it is prohibited to use the prestart heater indoors, unless there is a good ventilation system available.

When draining the cooling system of the engine, do not fail to open the drain cock of the prestart heater to drain its system as well. In summer time, the heater should be removed from the engine.

6.3. Cooling System Servicing and Troubles

To ensure that the engine cooling system will operate normally, one should observe the following rules.

Fill the cooling system only with clean, preferably soft water. Soft water can be recognized by its ability to form an immediate

lather with soap. It is recommended that use should be made of the water which has been already used in and drained from the system, for it contains less calcium salts. Hard water can be softened by boiling during 30 min and also by addition of washing soda (sodium carbonate) or trisodium phosphate (1 to 2 g per liter of hot water, depending on its hardness).

Fill the radiator to the level of the filler neck and never allow the coolant level to drop more than 8 cm below the filler neck.

If necessary, top up the coolant level of an overheated engine only gradually, keeping the engine running without fail. In winter time, do not use excessively hot water to fill the cooling system of a cold engine, because the sharp change in temperature may cause the cylinder head and block to crack.

Never operate the engine with the water temperature in the radiator exceeding 100°C.

Do not fail to check regularly, EVERY SHIFT, the water level in the radiator. When doing this, remove the radiator pressure cap with care, so as not to get your face and hands burned by the hot water and steam that may erupt from the filler neck. Should the water level in the radiator prove too low, top it up and check the system for possible leaks. An excessive water leakage from the drain hole in the water pump body indicates that the pump seal assembly components have worn out and must be replaced. If there are no water leaks, but the engine consumes too much water, check the condition of the radiator pressure cap.

EVERY 60 HOURS OF OPERATION lubricate the water pump bearings. To do this, clean the lubricator, fit the nipple of a grease gun to it, and pump the gun three or four times. Check the fan belt tension. The belt is considered to be tightened properly if it flexes 10 to 15 mm (15 to 20 mm in air-cooled engines) when a load of 30 to 40 N is applied to it midway between the crankshaft and fan pulleys. Use a drive-belt tension gauge to make the check. The fan belt tension is adjusted by changing the position of the generator (see Fig. 35*b*) or fan-belt tightener.

Remember that too tight a fan belt causes the bearings to wear out prematurely, while a slack belt causes the engine to overheat and wears off intensively.

Lubricant-contaminated belts should be cleaned with a wiping rag soaked with gasoline.

EVERY 960 HOURS OF OPERATION clean the cooling system with a special solution (e. g., 100 g of washing soda and 50 g of kerosene per liter of water) to remove scale. To do this, drain the system, fill it with the solution, and operate the engine for a full shift. Then drain the solution from the system and flush the system with clean water.

When servicing an air-cooled engine, clean the protective screen of the air blower and the cooling fins of the cylinder barrels and heads.

WHEN CARRYING OUT THE SEASONAL SERVICING PROCEDURES, test the thermostat and the coolant temperature gauge.

To test the thermostat, remove it from its housing, immerse in a container of water, and heat the water. At a temperature of 70°C the main valve should start to open, and when the water temperature reaches 85°C, the valve should be fully open. The full stroke of the valve should be around 9 mm. If the thermostat fails to open at the specified temperature, or if it fails to open to its maximum, it must be replaced.

To test the temperature gauge, check its readings against the readings of a mercury thermometer immersed in the radiator filler neck. Should the readings of the gauge be at variance with those of the thermometer, the gauge or its sending unit must be replaced.

Cooling system troubles usually manifest themselves in engine overheating. The causes of overheating may be the following: lack of coolant in the cooling system, closed radiator shutter or blind, scale and sludge accumulations in the cooling system, too loose or soiled fan belt, engine overload, faulty thermostat, and in some engines, broken lock pin of the water pump impeller.

In cold weather, water may freeze in the engine cooling system, thus stopping coolant circulation. Some parts of the engine will overheat if not cooled, and this could seriously damage the engine. What is worse, water

expands when it freezes. Water freezing in the cylinder block could expand enough to actually crack the block. Water freezing in the radiator could burst the radiator tanks and tubes. Therefore, under such conditions, water must be drained from the cooling system whenever the engine is stopped for any prolonged period of time, or an antifreeze solution must be used to fill the system.

Lately, the Tosol A-40 antifreeze solution has been recommended for use as a coolant. It should be used year-round in the engine cooling system and changed every two years. Keep in mind that the antifreeze is very toxic and will cause poisoning if ingested. Therefore, do not fail to wear rubber gloves when pouring the antifreeze solution, never use your breath to pull it into a siphon hose, and neither smoke nor eat when handling the solution in any way.

The causes of overheating of air-cooled engines may be a slack, contaminated, or worn fan belt, a clogged protective screen of the air blower, or clogged airways between the cooling fins of the cylinder barrels and heads.

Review Questions

1. List the main components of the engine cooling system.
2. Using Fig. 33, explain the operation of an air cooling system.
3. What is the purpose of the thermostat?
4. What is the purpose of the valves in the radiator pressure cap?
5. How is the fan belt tension checked and adjusted?
6. Outline the methods for softening hard water.
7. How is scale removed from the cooling system?
8. How is the operation of the thermostat and coolant temperature gauge checked?
9. Name the causes of water overheating in the engine cooling system.
10. Describe the construction and operation of the prestart heater.

Chapter 7
The Lubrication System

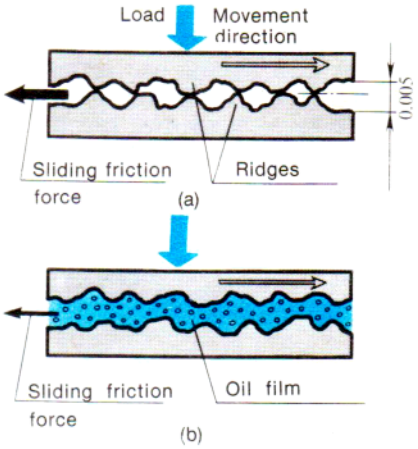
7.1. General

During operation, the movable engine components slide or roll over stationary ones. The rubbing surfaces of the engine components, despite their being machined to a high degree of finish, have irregularities or asperities (Fig. 38). The surface irregularities of the working parts in rubbing contact interlock or cohere, so that the friction force opposing the relative motions of the parts is increased, thus reducing the engine power. Dry friction is attended by increased heating and accelerated wear of the working parts. To reduce friction and, at the same time, cool the parts, a film of lubricating oil is introduced between the rubbing surfaces of the parts. The oil film keeps the surfaces apart, thereby providing a condition of fluid friction instead of dry friction. With fluid friction, there is no direct contact between the surfaces of parts in relative motion, hence friction losses in the film of oil are much smaller than those generated by dry friction, and wear of the parts is greatly reduced.

The purpose of the engine lubrication system is to supply oil continuously to the rubbing engine parts and remove heat from them.

ENGINE OILS. The working parts of automotive engines are lubricated with high-quality engine oils. These oils must possess an optimum viscosity, high lubricity, or oiliness, good antricorrosive properties, and high stability. To improve the service properties of engine oils, they are treated with special additives.

According to the new engine oil classification system adopted in this country, engine oils are classed in six groups: А, Б, В, Г, Д, and Е. The engines of farm tractors and automobiles use oils belonging to groups Б, В, and Г. Group Б oils are intended for light-duty engines, group В oils – for moderate-duty engines, and group Г oils – for severe-duty engines. Under this classification system, various grades of engine



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Illustrating friction
(a) dry friction;
(b) fluid friction

oil are designated by symbols including both letters and numerals, for example, М-8 $Б_1$, М-10 $Г_2$. In these symbols of grades, the letter М means engine oil, the numerals 8 and 10 indicate the kinematic viscosity of the oils at 100°C in mm^2/s, the letters Б and Г denote the classification groups the oils belong to, the subscript 1 shows that the oil is intended for use in carburettor engines, and the subscript 2, in diesel engines.

Viscosity is a very important characteristic of engine oils, for it determines their ability to flow. An oil with excessively high viscosity is very thick, and it is difficult for it to penetrate the clearances between the rubbing engine parts, while an oil with too low viscosity flows easily and does not stay in the clearances. In both cases, wear on the rubbing surfaces of the working parts is intensified and the engine power is reduced. Oil gets thicker as it becomes colder. Therefore, oils with a viscosity of 10 mm^2/s are usually used in summer and those 8 mm^2/s in viscosity, in winter. It is essential that the oil used should strictly comply with the particular engine specifications and the season.

The reliable operation of engines largely depends on the purity of the engine oils used. The oils must be free from mechanical impurities and water. These contaminants get into the oils mainly during shipment, reception, dispensing, and storage. Crankcase oils are especially prone to contamination with mechanical impurities where the engines are run in conditions of the ambient air heavily laden with dust. Therefore, when handling engine oils every measure must be taken to prevent their being contaminated with mechanical impurities and water.

ENGINE LUBRICATION SYSTEM. The engines studied in this book use a combined lubrication system whereby the engine components that are loaded most heavily are lubricated by forced oil circulation, while other, less loaded parts, are lubricated by splash and by gravity.

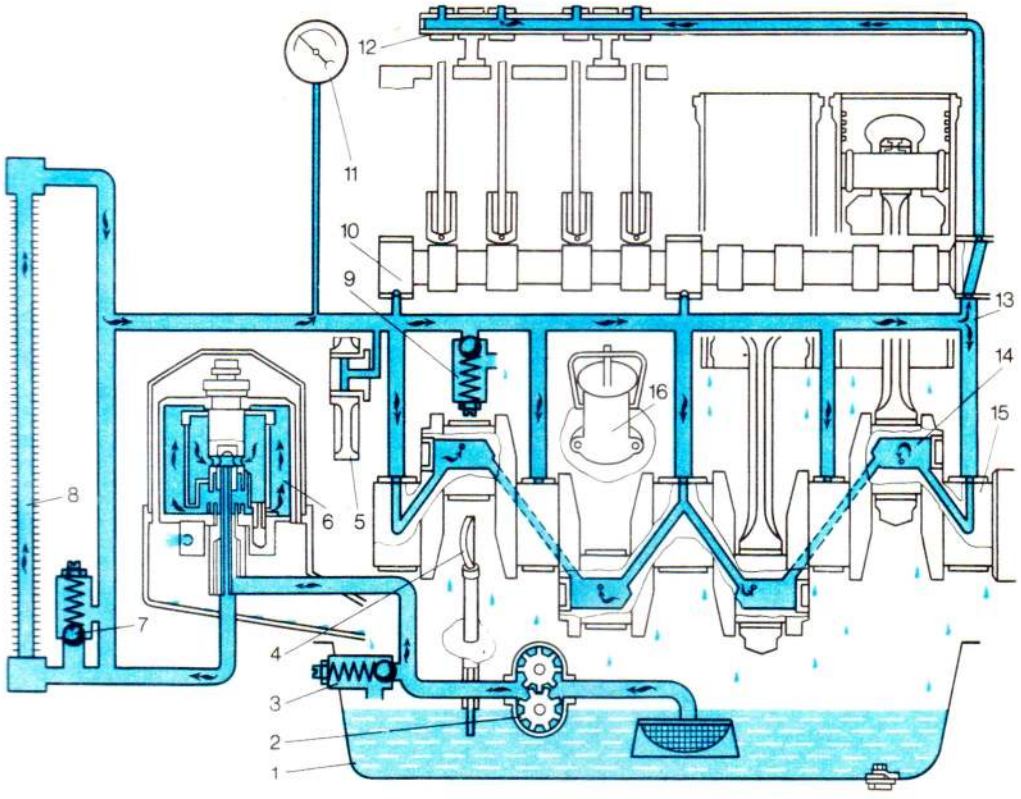
Lubricated by forced oil circulation are the crankshaft main bearings and connecting rod big-end bearings, the valve mechanism, the camshaft bushings, and timing gear bushings.

The engine lubrication system (Fig. 39) includes oil pan *1*, oil pump *2*, oil filter *6*, oil cooler *8*, oil ducts and lines, oil pressure gauge *11*, and oil filler *16*. The oil level in the crankcase is checked with dipstick *4* when the engine stands still.

The forced oil circulation circuit in most automotive engines is the same. Figure 39 illustrates schematically the operation of the engine lubrication system. With the engine running, the crankcase oil is drawn by the gear-type oil pump which delivers it under pressure to the oil filter. The clean oil leaving the filter is cooled in the oil cooler, whence it passes into main oil gallery *13*. From the main oil gallery the oil flows through ducts in the cylinder block to the crankshaft main bearings and the camshaft bearing journals.

Flowing through the angular oil passages drilled in the crankshaft, the oil enters crankpin oil cavities *14*, where it is additionally cleaned, and emerges on the crankpin surfaces to lubricate the connecting rod bearings. From the first crankshaft main bearing the oil is ducted to the spindle of idler gear *5* and the fuel pump drive gear bushing.

Through a cross-drilling in one of the camshaft bearing journals the oil is fed



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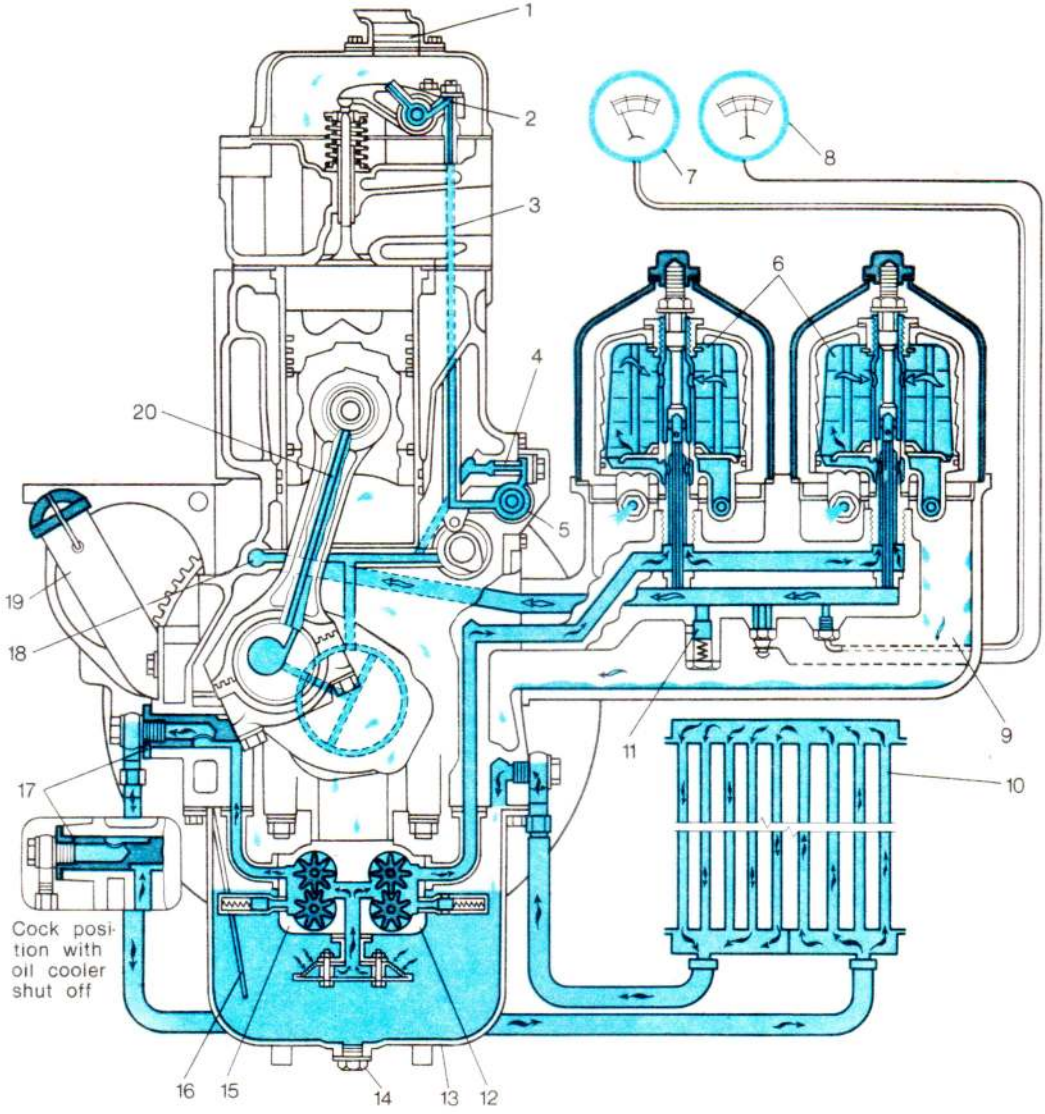
Schematic diagram of an engine lubrication system

1 – oil pan;
2 – oil pump;
3 – pressure relief valve;
4 – oil level dipstick;
5 – idler gear;
6 – oil filter;
7 – oil cooler by-pass valve (temperature controlled);
8 – oil cooler;
9 – drain valve;
10 – camshaft;
11 – pressure gauge;
12 – rocker-arm shaft;
13 – main oil gallery;
14 – crankpin oil cavity;
15 – crankshaft;
16 – oil filler

intermittently into hollow rocker-arm shaft *12* by a duct extending upwards through the cylinder block and cylinder head and an external supply pipe. The oil is distributed to each rocker bearing bushing through radial drillings in the rocker-arm shaft. The oil escaping from the rocker bearings runs down the push-rods to lubricate the valve lifters and cams.

The cylinder walls, piston skirts and pins, and timing gears are lubricated by splash. With the crankshaft rotating rapidly, the oil escaping from the crankshaft bearings and that draining from the valve mechanism is flung off in fine droplets from the big end bearings to form an oil mist. The oil droplets setting onto the surfaces of the cylinders, pistons, and cams lubricate them and run down into the oil pan, whence the oil starts again on its circuit. The piston pin is lubricated with the oil droplets that get into the hole in the connecting rod small end. In engines having oil passages drilled through their connecting rods, the piston pins are lubricated by forced oil circulation.

The operation of the engine lubrication system is monitored by watching pressure gauge *11* that reads the oil pressure in the main oil gallery. Some engines are additionally equipped with an oil temperature gauge and an



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Lubrication system of the A-41 Model tractor engine

1 – breather;
2 – rocker arm;
3 – push-rod;
4 – hollow bolt;
5 – pivoting cam follower;
6 – oil filter sections;
7 – pressure gauge;
8 – temperature gauge;
9 – oil filter;
10 – oil cooler;
11 – relief valve;
12 – oil pump main section;
13 – oil pan;
14 – drain plug;
15 – oil pump cooler section;
16 – oil level dipstick;
17 – two-way cock;
18 – main oil gallery;
19 – oil filler;
20 – connecting rod oil passage

oil pressure indicator light. The light is off when the oil pressure is normal. But if the pressure drops too low, the light comes on.

Figure 40 shows the lubrication system of a tractor engine with pivoting cam followers *5*. The system uses a duplex oil pump. From oil pump main section *12* oil is delivered to twin oil filter *9*, with its two sections operating in parallel. Some of the oil cleaned in the filter is drained, after being used to drive the filter rotors, to the oil pan. The rest of the cleaned oil is supplied under pressure into main oil gallery *18*. whence it is ducted to the rubbing engine components, as described above. The valve mechanism is lubricated with the oil supplied through hollow bolt *4*, pivoting cam follower *5*, and hollow push-rod *3*.

Oil pump cooler section *15* delivers oil to cooler *10*, whence the cooled oil drains into the oil pan. In winter time, the oil delivered by the cooler section of the oil pump can be made to flow direct into the oil pan, by-passing the oil cooler. This is done by turning the handle of two-way cock *17* through 180°.

The engine crankcase is filled with oil through filler *19*. It is recommended that after filling the crankcase with oil, the engine should be run for two or three minutes to fill the entire lubrication system. Then the engine should be stopped, and the oil should be allowed to drain (for 10 minutes) into the oil pan. After that, the oil level in the oil pan should be checked.

To check the level of the oil in the oil pan, use is made of dipstick *16*. To use the dipstick, pull it out, wipe it off, and put it back in place. Then pull it out again so that you can check the level of the oil shown on the dipstick against the markings stamped in its lower part. With the engine standing still, the oil level should register with the upper marking on the dipstick. If the oil level stays below the lower marking on the dipstick when the engine is stopped, the engine must not be started until the crankcase is topped up. The excess oil, if any, is drained from the crankcase through the hole in the oil pan that is closed by plug *14*.

7.2. Lubrication System Components

OIL PUMP. This is a gear-type pump intended to induce oil circulation in the engine lubrication system. It is usually bolted to a boss on the lower face of the crankcase or to a crankshaft main bearing cap.

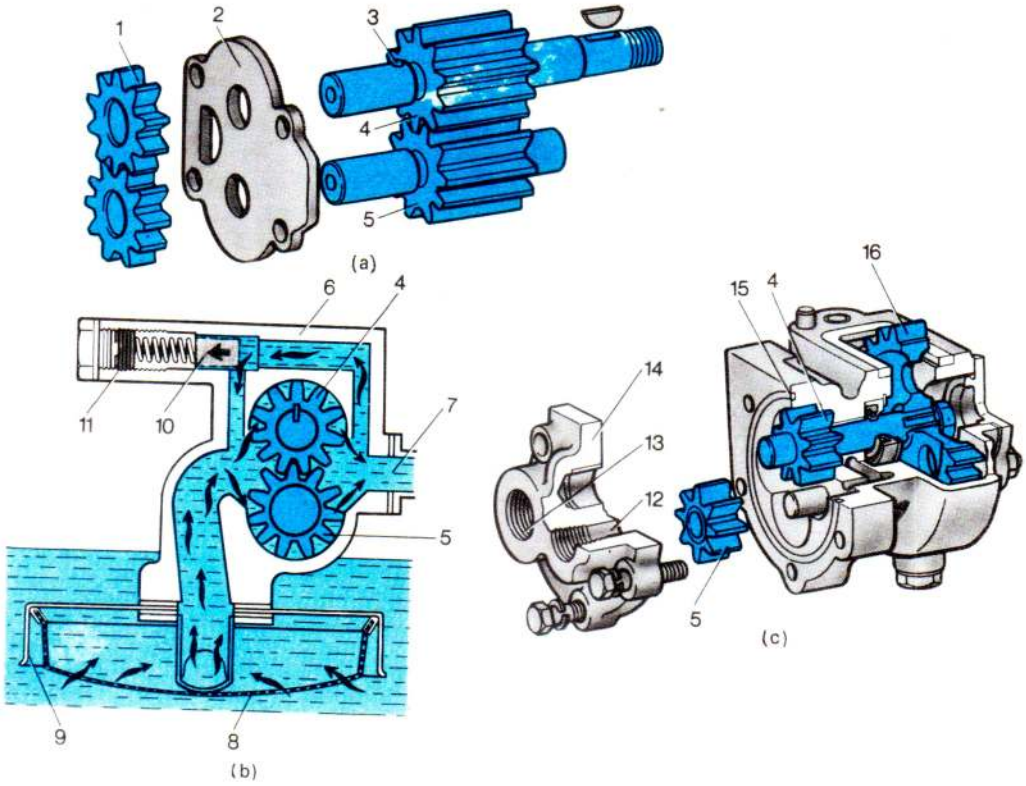
The pumps used in engine lubrication systems may be either of duplex type (Fig. 41*a*) or of simplex type (Fig. 41*b*). The duplex-type oil pump comprises two sections – the main section and the cooler section – separated by spacer plate *2*. Each pump section operates independently of the other, like a simplex pump.

The simplex-type oil pump consists of oil pick-up *9*, housing *6*, end cover *14*, and a pair of gears. Machined in the pump housing are two overlapping cylindrical wells to accommodate the pump gears. Driving gear *4* of the pump is keyed to the pump drive shaft which is supported by two bushings pressed in the housing of the pump and its end cover. Driven gear *5* meshes with the driving gear and is free to rotate on a fixed spindle pressed in the pump housing. In operation, the oil entering the pump through the inlet port in the housing becomes trapped between the teeth of the contra-rotating gears and the surrounding wall of the pumping chamber. The oil is thus carried around the periphery of the gears (not between them) and then discharged through opposite discharge port 7. At this point, the action of the intermeshing teeth prevents the oil from returning to the inlet side of the pump.

A bored boss provided on the pump housing accommodates poppet-type pressure relief valve *10*. The latter prevents the pump delivery pressure from rising too high when starting the engine from cold, i. e., when the viscosity of the crankcase oil is high. The setting of the pressure relief valve can be adjusted by varying the spring load on the poppet with the aid of adjusting screw *11*.

The oil pump in tractor engines is driven from a gear on the nose of the crankshaft, while in automobile engines, it is driven from a gear made integral with the camshaft.

Some tractor engines that are started with



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Oil pump

(a) duplex;
(b) simplex;
(c) prestart;
1 – cooler section driving gear;
2 – spacer plate;
3 – drive shaft;
4 – main section driving gear;
5 – main section driven gear;
6 – housing;
7 – discharge port;
8 – oil pick-up wire gauze screen;
9 – oil pick-up;
10 – pressure relief valve;
11 – adjusting screw;
12 – outlet port;
13 – inlet port;
14 – end cover;
15 – housing
16 – oil pump drive gear

the aid of a starting engine use a prestart oil pump (Fig. 41*c*) to feed oil into the lubrication system of the main engine when operating the starting engine. Drive gear *16* of the prestart oil pump meshes permanently with the crankshaft gear of the starting engine. Therefore, after the engine has started, the prestart oil pump gears draw oil from the oil pan of the main engine through an intake pipe and a non-return valve and deliver it into the oil line of the main engine. After the main engine has started, the pressure in the oil line increases and causes the non-return valve to close, thus shutting off the oil supply to the prestart oil pump.

OIL COOLER. The purpose of the oil cooler is to cool oil in summer time. It is a one-piece unit consisting of a series of steel tubes of a flattened oval section and two tanks: a top tank and a bottom tank. To enlarge the cooling surface area, a spiral of thin steel ribbon is wound around each cooler tube. The oil coolers of some engines have their tubes passing through a large number of flat cooling fins, and their tanks are divided into several compartments by partitions. Welded to the tanks are the inlet and outlet oil pipe connections and mounting lugs. The oil cooler is mounted in front of the cooling system radiator. In air-cooled engines, the oil cooler

takes the form of a single tube repeatedly bent in and out and carrying a ribbon spiral wound around it. With the radiator shutter or blind fully open, the oil flowing through the cooler tubes that are exposed to the through flow of cooling air on the outside gets colder by 10 to 12°C.

OIL FILTER. To remove mechanical impurities from the oil circulating through the engine lubrication system, use is made of the oil filter. Modern automotive engines mostly use centrifugal oil filters.

In centrifugal oil filters (Fig. 42), oil is cleaned under the effect of centrifugal forces arising as a result of rotation of the filter rotor, or bowl.

The main component parts of a reaction-type centrifugal oil filter (Fig. 42*a*) are rotor *1* and spindle *3* whose lower part is screwed into the filter body. The filter acts as follows. From the oil pump oil is forced into the rotor through axial and radial holes in the spindle. From the rotor the oil passes through oil intake tubes *4* to calibrated orifices – jet nozzles *6* and flows out of them with a high velocity. The repulsive action (reaction) of the jets of oil issuing from the nozzles causes the rotor to revolve in the opposite direction. The oil flowing out of the jet nozzles into the filter housing is drained into the engine crankcase.

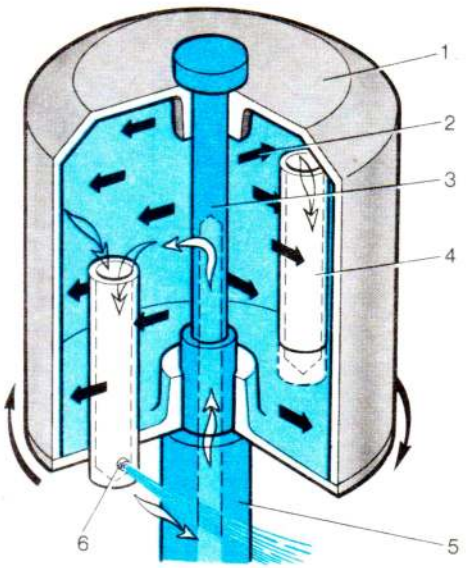
At the normal oil pressure the rotor revolves with a frequency of 630 rad/s (6000 rpm). The rapid rotation of the filter rotor subjects the oil entering it to a high centrifugal force which throws the heavier contaminants contained in the lighter oil to the rotor walls where they are deposited in a dense, tarry layer.

Engines of more recent designs use a *full-flow centrifugal oil filter*. This is a reaction-type centrifugal filter with which all of the oil delivered by the oil pump is cleaned in the filter rotor. As distinct from the centrifugal oil filter considered above, this filter has oil outlet pipe *10* fitted inside hollow spindle *9* of the filter rotor and connected to the oil line that distributes the oil to the various parts of the lubrication system.

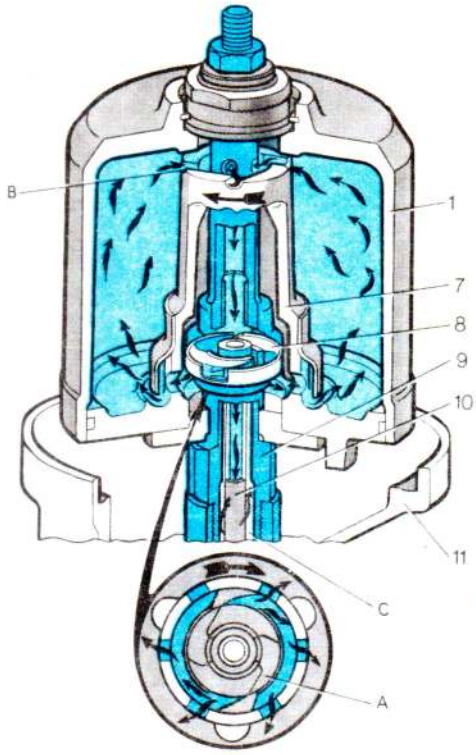
During engine operation, the oil delivered by the oil pump enters the annular space between the rotor spindle and the outlet pipe via ducts provided in the filter housing. From this space the oil passes into the rotor through radial holes in the rotor spindle and body. Inside the rotor, the flow of the cleaned oil is divided. Some of the oil (around 20%) goes to drive the rotor and flows out of nozzles *6* into the engine crankcase. The major part of the oil passes through a series of radial holes in the upper portion of the rotor body and spindle into outlet pipe *10* and thence into the oil line. In the full-flow centrifugal oil filter, there are no oil intake tubes in the filter rotor.

Some engines use a new, *impulse-reaction centrifugal oil filter* (Fig. 42*b*). In contrast to the reaction-type filter, this type of oil filter has no jet nozzles, and the oil used to drive the filter rotor does not drain to the oil pan but goes instead to lubricate the working parts of the engine. Rigidly fixed to rotor spindle *9* of this filter is oil swirler insert *8* having oil ducts *A* tangent to its circumference. The upper part of rotor body *7* is in turn provided with a series of tangential oil ducts *B*.

The oil pump delivers contaminated oil under a pressure of 0.6 to 0.7 MPa into the annular space *C* between the rotor spindle and the oil outlet pipe and thence into the ducts *A*. Issuing from these ducts under pressure, jets of oil tangent to the inner wall of the rotor body produce a torque that makes the rotor revolve in the direction of the oil flow, as shown by an arrow in Fig. 42*b*. Under the action of centrifugal forces the mechanical impurities contained in the oil are deposited in the form of a tarry layer on the inner walls of the revolving rotor. The cleaned oil is ejected with a high velocity through the tangential ducts *B* in the upper part of the rotor and then passes through radial holes into the oil duct of the fixed rotor spindle and thence into the oil line. The jets of oil emerging from the tangential ducts *B* develop a reaction torque which also forces the filter rotor to revolve. Thus, the rotation of the filter rotor is due to the combined action of two streams of oil: the direct action of the oil stream entering the rotor via the ducts *A* and the reaction of the oil stream leaving the rotor via the ducts *B*.



(a)



(b)

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Illustrating the operation of a centrifugal oil filter

(a) reaction-type filter;
(b) impulse-reaction-type full-flow filter;
1 – rotor;
2 – mechanical impurities;
3 – spindle;
4 – oil intake tube;
5 – oil supply line;
6 – jet nozzle;
7 – rotor body;
8 – oil swirler insert;
9 – hollow spindle;
10 – oil outlet pipe;
11 – filter housing;
A and B – oil ducts;
C – annular space

In centrifugal oil filters (Fig. 43) the rotor consists of body *16* and bowl *17*. The surface area of the rotor top is greater than that of the bottom, because the diameter of the upper journal of the rotor spindle is greater than that of the lower journal. The total oil pressure force acting on the rotor top from below is greater than the force acting on the bottom. Therefore, when the engine is running, the rotor is lifted and its bearing end face is thus relieved. The higher the pressure in the rotor, the greater the distance the rotor is lifted through. The maximum lift of the rotor is kept within 0.3 to 1.5 mm by thrust washer *18*.

The filter housing incorporates three valves: filter by-pass valve *12*, oil cooler by-pass valve *4* and relief valve *8*.

THE OIL FILTER BY-PASS VALVE maintains the pressure in the filter rotor at a definite level. If the oil pressure at the inlet to the rotor grows as high as 0.65 MPa (with the oil too thick or the rotor contaminated excessively), the valve opens and unfiltered oil flows into the engine crankcase. In some engines, the valve by-passes the oil to the engine oil line. The filter by-pass valve is set to open at a pressure of 0.65 to 0.7 MPa by means of adjusting screw *10*.

THE OIL COOLER BY-PASS VALVE makes cold oil by-pass the oil cooler and flow directly to the oil passages of the engine. The valve is permanently set to open at a pressure differential of 0.06 to 0.07 MPa.

THE RELIEF VALVE serves to drain the excess filtered oil into the engine crankcase should the

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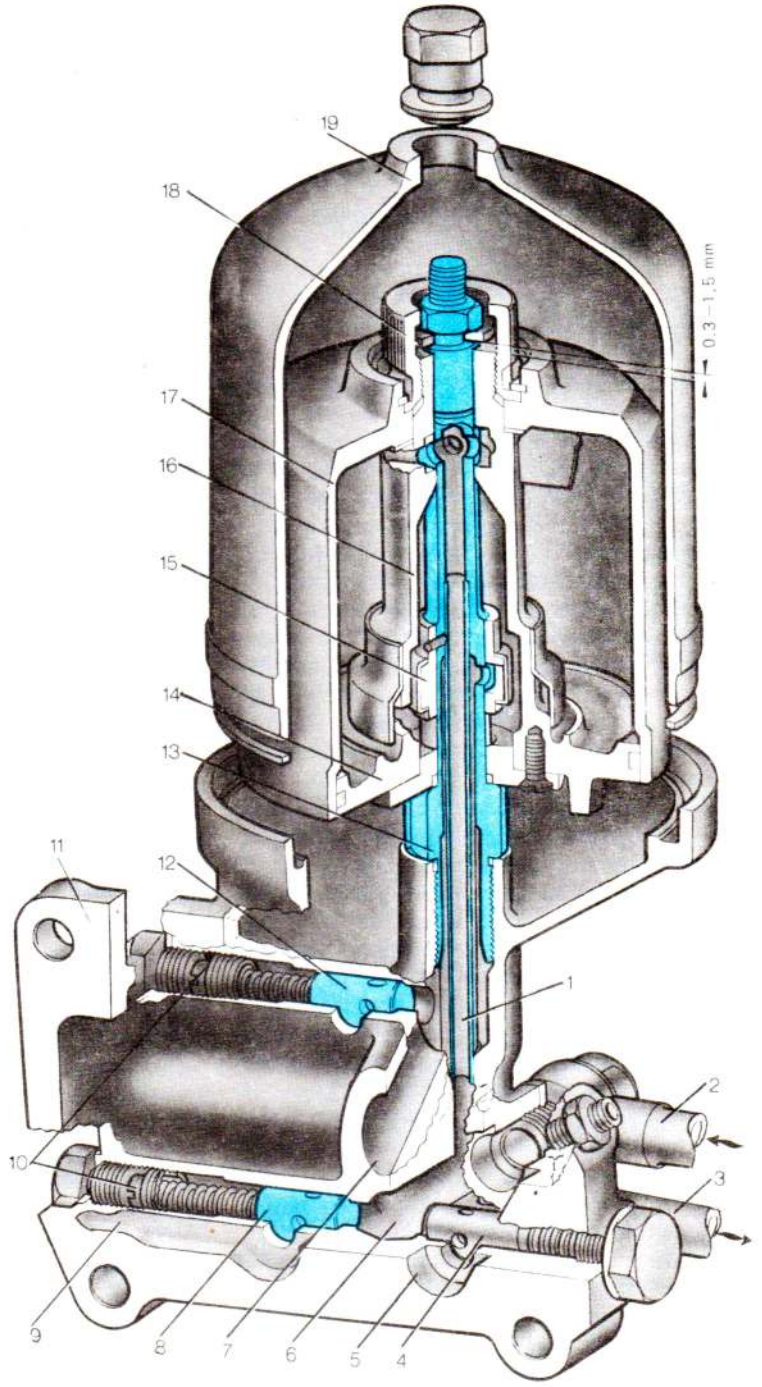
Full-flow oil filter

1 – oil outlet pipe;
2 – oil cooler outlet pipe;
3 – oil cooler inlet pipe;
4 – oil cooler by-pass valve;
5 and 6 – clean oil outlet ducts;
7 – contaminated oil inlet duct;
8 – relief valve;
9 – drain cavity;
10 – valve adjusting screws;
11 – oil filter housing;
12 – oil filter by-pass valve;
13 – hollow spindle;
14 – cover;
15 – oil swirler insert;
16 – rotor body;
17 – rotor bowl;
18 – thrust washer;
19 – hood



pressure in the oil passages of the engine rise too high. The valve is set by adjusting screw *10* to maintain the normal oil pressure in the lubrication system.

The oil filters of some engines are equipped with a two-way cock instead of the oil cooler by-pass valve. The cock is used to disconnect the oil cooler from the lubrication system in winter time.

7.3. Lubrication System Servicing and Troubles

The useful service life of the engine largely depends on the purity of the oil the engine is lubricated with. Contaminated oil makes the rubbing surfaces of the engine working parts wear rapidly. The crankcase oil can be most simply checked for quality (purity) by the following method. Apply a few drops of the oil onto a sheet of white, preferably filter paper. If the oil is contaminated, it will leave, while spreading over the paper, a dark spot in the center of the sheet, which indicates that the active oil additives separate from the oil. In clean oil, the additives are held in fine suspension and will form a ring on the filter paper.

The servicing of the engine lubrication system involves the following procedures: checking the oil level in the engine crankcase, checking all the connections of the system for leaks, monitoring the oil temperature and pressure while warming the engine up and while running it under load, flushing the system, and changing the crankcase oil.

As a matter of routine maintenance of the lubrication system of his tractor or automobile engine, the driver must check the crankcase oil level EVERY SHIFT, but not earlier than 10 min after the engine has been stopped, and top up the system should the oil level prove to be below the upper marking on the dipstick; check the system for oil leaks and eliminate any leaks revealed; watch the readings of the oil pressure gauge during engine operation; check the operation of the centrifugal oil filter by listening to its rotor after the engine has been stopped. If the noise produced by the filter rotor revolving by inertia lasts for less than 30 s (this indicating that the rotor is excessively contaminated), the filter must be disassembled and the jet nozzles of its rotor cleaned.

EVERY 120 HOURS OF OPERATION the rotor of the centrifugal oil filter must be cleaned. To do this, remove the filter hood and rotor from the spindle, disassemble the rotor, remove deposits from the rotor walls and wash all the component parts of the rotor with diesel fuel; use a length of copper wire 1.5 mm in diameter to clean the jet nozzles of the rotor. Then reassemble the rotor, making sure that the sealing ring of the rotor bowl is placed correctly in its groove in the rotor body, and install the rotor and filter hood in place.

EVERY 240 HOURS OF OPERATION the oil in the engine lubrication system must be changed. Before filling it with fresh oil, the system must be flushed with a mixture of 80% diesel fuel and 20% engine oil. This is done with the aid of a special plant when the engine is stopped.

EVERY 960 HOURS OF OPERATION the oil pan and the oil pick-up of the oil pump must be removed from the engine and washed clean with diesel fuel.

THE MOST COMMON LUBRICATION SYSTEM TROUBLES are as follows: no oil pressure, too low or too high oil pressure, oil contamination with coolant, and oil leaks.

The absence of oil pressure in the system may be caused by low oil level in the oil pan, stuck pressure relief valve of the oil pump, or faulty oil pump drive. These troubles can be removed by adding oil to the oil pan, washing the pressure relief valve, or repairing the oil pump drive, respectively.

Low oil pressure in the system may be caused by lack of oil in the oil pan, enabling air to enter the oil pump, low viscosity of the oil as a result of its overheating, dilution with fuel, or incompatibility with the engine requirements, clogged oil pick-up screen, weak or broken pressure relief valve spring of the oil pump or oil filter, worn oil pump components, or large crankshaft bearing clearances.

To remove the trouble, it is necessary to eliminate successively its causes: add oil to the oil pan, eliminate the causes of oil overheating

or change the oil in accordance with the engine manufacturer's recommendations, remove the oil pan and wash clean the oil pick-up screen, wash clean and adjust the pressure relief valve of the oil pump or oil filter, and, if necessary, replace the crankshaft bearing inserts.

High oil pressure in the lubrication system may be caused by high viscosity of the oil or stuck pressure relief valve of the oil filter. To remove the trouble, it is necessary to disconnect the oil cooler from the system, check the oil viscosity and change the oil, if need be, and check the relief valve of the filter and eliminate the causes of its sticking, if any.

If the engine coolant gets into the crankcase oil, one should first of all tighten up the cylinder head nuts and, if necessary, replace the sealing gaskets between the cylinder liners and the cylinder block.

Oil leaks are eliminated by tightening up the respective fasteners and, if necessary, replacing damaged sealing gaskets or leaky components.

Review Questions

1. What oil is used to lubricate automotive engines?
2. List the component parts of the engine lubrication system.
3. Trace in Fig. 39 the route of oil to the rubbing parts of the engine.
4. What is the purpose of the oil pump pressure relief valve?
5. How is the oil cleaned from mechanical impurities in the centrifugal oil filter?
6. What are the valves incorporated in the oil filter housing and what is their purpose?
7. How is the oil level in the engine crankcase checked and how is the oil added to the crankcase?
8. What is used to adjust the oil pressure in the engine lubrication system?
9. When is the crankcase oil changed?
10. How is the centrifugal oil filter checked for contamination without disassembling the filter?
11. How can the purity of the crankcase oil be checked?
12. List the causes of low oil pressure in the engine lubrication system.

Chapter 8
The Fuel System

8.1. General

The fuel systems of diesel and carburettor engines differ in principle.

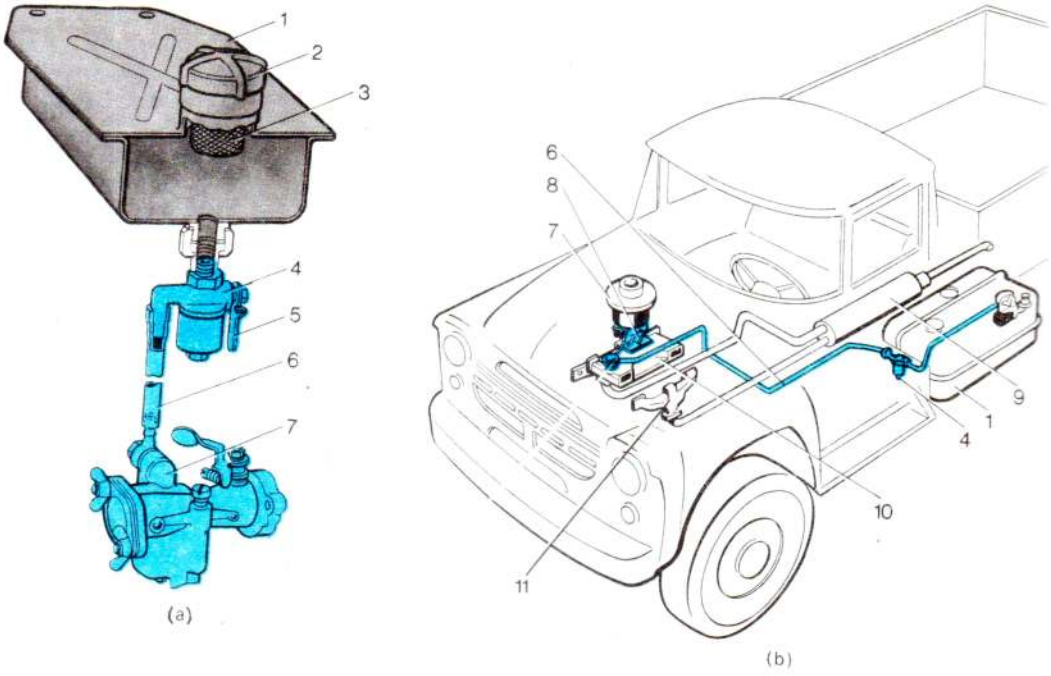
IN THE CARBURETTOR ENGINE, the combustible mixture of required composition is prepared from air and fuel in a special device – carburettor – and is then delivered in desired amounts to the individual cylinders of the engine.

In tractor starting engines (Fig. 44*a*), fuel is fed by gravity from tank *1* to carburettor *7* through combination fuel filter and sediment trap *4*.

In automobile carburettor engines (Fig. 44*b*), fuel is drawn from tank *1* through combination fuel filter and sediment trap *4* and a fuel line by pump *11* which delivers it to carburettor *7*. On the intake stroke, atmospheric air is drawn into the carburettor through air filter (cleaner) *8* where it is cleaned of foreign matter. In the carburettor, the incoming air is mixed with finely atomized fuel and then passes into intake pipe (manifold) *10*. The preparation of the air-fuel mixture continues in the intake pipe where the fuel evaporates and mixes more intimately with the air. The process ends in the engine cylinders during the intake and compression strokes. After the combustible charge has burned, the burnt gases are expelled into the atmosphere through the exhaust pipe (manifold) and muffler *9*.

The automobile carburettor engines operate mainly on gasoline (petrol). To obtain a satisfactory engine performance with reasonable fuel economy, the gasoline fuel must possess adequate volatility and knock resistance.

Combustion knock also is called detonation. *Detonation* is an extremely rapid, explosion-like combustion of the fuel in the engine cylinders. The engine must not be allowed to knock, for this condition is attended by heavy impact loads on the pistons, piston pins, and crank-



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Fuel system of a carburettor engine

(a) of a starting engine;
(b) of an automobile engine;
1 – fuel tank;
2 – fuel tank filler cap;
3 – filter gauze;
4 – fuel filter and sediment trap;
5 – handle;
6 – fuel line:
7 – carburettor;
8 – air filter;
9 – muffler;
10 – intake and exhaust manifolds;
11 – fuel pump

shaft main and connecting rod bearings and leads to local overheating of the engine components, burning of pistons and valves, smoky exhaust, loss of engine power, and increased fuel consumption. The onset of detonation is related not only to the knock resistance of the fuel, but also to the engine speed and load conditions, carbon deposition on the pistons and the cylinder head, ignition timing, etc.

The knock resistance of gasoline fuels is evaluated in terms of their octane number, or rating. The octane number of a fuel is determined by comparing its knock resistance with the knock resistance of a blended reference fuel of known octane rating. The reference fuel is a mixture of two fuels: heptane and isooctane. Heptane has a low knock resistance and its octane rating is arbitrarily taken to be zero. On the other hand, the knock resistance of isooctane is high, and its octane rating is arbitrarily set at 100.

The octane number of a fuel is defined as the percentage by volume of isooctane in such a mixture of isooctane and heptane as is equal to the test fuel in knock resistance. For example, if a mixture of 76% isooctane and 24% heptane is equal in knock resistance to the test gasoline, the octane number of the gasoline will be 76. The higher the octane rating of a fuel, the higher its knock resistance.

In this country, automobile gasoline is available in five grades: A-66, A-72, A-76, АИ-93, and АИ-98. The letter A in the grade symbols means automobile-grade gasoline, and the numerals indicate the octane number of the gasoline. Except for the АИ-98 gasoline.

automobile gasoline fuels are available in both summer and winter grades.

To enhance the knock resistance of gasoline, it is sometimes treated with an antiknock additive (ethyl fluid – tetraethyl lead, or "tel"). The A-72 Grade gasoline is not ethylated. The other grades of gasoline may be both ethylated (leaded) and clear (unleaded). The ethylated grades of gasoline are coloured orange (A-66), green (A-76), blue (АИ-93), or yellow (АИ-98).

When handling gasoline, one should strictly observe safety regulations, because gasoline is readily flammable. Being a good solvent, gasoline may damage painted surfaces and rubber components. Special caution should be exercised in handling ethylated gasoline, for it may cause lead poisoning if gets into the human body. It is prohibited to use ethylated gasoline for washing hands, clothing, or engine parts, or to suck it into a siphon hose. Should ethylated gasoline get onto the skin, the contaminated skin area must be washed first with kerosene and then with soap and water.

THE FUEL SYSTEM OF A DIESEL ENGINE serves to supply clean air and atomized fuel into the engine cylinders.

In diesel engines, the formation of the air-fuel mixture occurs in a very short period of time. To make the mixture capable of burning rapidly and completely, it is essential that the fuel be broken into as fine particles as possible and that the amount of air surrounding each fuel particle be sufficient for its complete combustion.

To this end, the fuel is injected into the cylinder by a fuel injector, the injection pressure being several times the air pressure in the combustion chamber at the end of the compression stroke. Modern tractor engines use open, or direct-injection, combustion chambers. Such a combustion chamber is a continuous space delimited by the piston head and the surface of the cylinder head and walls. It is formed in part by a bowl, usually of torroidal shape, in the piston head, which makes the cylinder air eddy, as the piston approaches TDC on the compression stroke. To facilitate the mixing of air and fuel, the shape of the open combustion chamber is made to match the fuel spray configuration.

To achieve complete combustion of the fuel, hence the best performance characteristics of the diesel engine, the fuel must be injected into the cylinder before the piston reaches TDC on the compression stroke, so that the peak cylinder pressure may be attained shortly after TDC on the power stroke. The actual duration of the injection period is controlled by the fuel injection pump, in accordance with power requirements.

Figure 45 shows a schematic diagram of the fuel system of a tractor diesel engine. During engine operation, the fuel is fed by gravity from fuel tank *9* to primary fuel filter *5* where it is cleaned from coarse mechanical impurities. From the primary filter the fuel is drawn by fuel transfer pump *12* and is delivered to fuel injection pump *14* through secondary fuel filter *6*. The fuel injection pump supplies fuel under a high pressure via fuel injection lines *4* to fuel injectors *3* through which atomized fuel is injected into the engine combustion chambers. The fuel injection pump is fed with fuel in abundance. The excess fuel is by-passed to the intake side of the fuel transfer pump through a relief (by-pass) valve incorporated in the connection adapter of by-pass pipe *13* on the fuel injection pump.

The leak-off fuel (up to 0.02% of the total fuel consumed) that passes through the closely controlled clearances of the fuel injector components to lubricate the nozzle valve returns through leak-off pipe *2* to the secondary oil filter or to the fuel tank. The fuel pressure at the outlet of the secondary fuel filter is monitored by means of a pressure gauge, and must be in the range 0.06 to 0.09 MPa.

Diesel engine fuel is an oily, light-brown liquid obtained from fractional distillation of crude oil (petroleum).

For a diesel engine to have optimum performance characteristics and long useful service life, the fuel used must meet certain requirements. The fuel must be free from contaminants, high in heating value, low in viscosity and flash point, and high in cetane number (not below 40). The cetane number of a diesel fuel is a measure of its ignition

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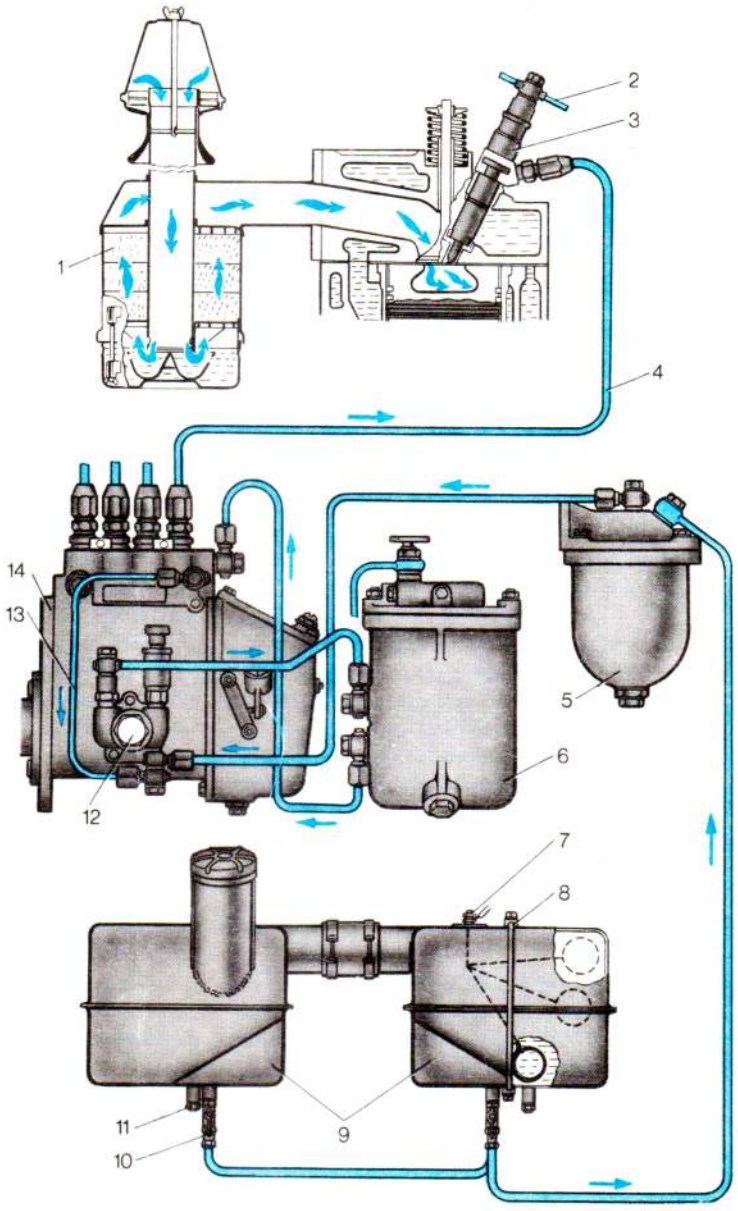
Fuel system of the Д-240 Model diesel engine

1 – air cleaner;
2 – leak-off pipe;
3 – fuel injector;
4 – fuel injection line;
5 – primary fuel filter;
6 – secondary fuel filter;
7 – fuel level sender;
8 – fuel level dip tube;
9 – fuel tanks (main and auxiliary);
10 – shut-off cock;
11 – drain cock;
12 – fuel transfer pump;
13 – fuel injection pump by-pass pipe;
14 – fuel injection pump



characteristics. The higher the cetane number, the shorter the ignition delay period, hence the smoother the engine operation. The cetane number is defined as the percentage by volume of cetane in a mixture of cetane (which is given a value of 100) and alpha-methylnaphthalene (whose value is taken at 0) that is equal to the test fuel in ignition quality.

The grades of diesel fuel used in tractor engines in this country are listed in Table 1.

The presence of sulphur in the diesel fuel shortens the ignition delay period and thus

Table 1

Characteristics	Fuel Grades					
		USSR Std. GOST 305-73		USSR Std. GOST 4749-73		
	Л	З	А	ДЛ	ДЗ	ДА
Minimum ambient temperature at which engine can run on given fuel, °C	0	– 20	– 30	0	–20	–50
Flash point, °C	310	240	240	310	240	230
Pour point, not lower than, °C	– 10	–35	– 45	–10	–45	–55
Sulphur content, %	From 0.2	up to 0.5		Not higher than 0.2		

reduces engine roughness and knock, but excessive sulphur content in the fuel may cause deposits and corrosion. These deposits will increase wear of cylinders, pistons, and piston rings. The corrosion is caused when sulphur produced during combustion combines with the water of combustion to form strong acids which attack the engine components. Therefore, the sulphur content of diesel fuels is limited in this country to 0.2 or 0.5% and is indicated on delivery by adding the corresponding numerals to the letter symbols of grades. For example, summer diesel fuel Grade Л-0.2 or winter diesel fuel Grade З-0.5.

The letters in the symbols of grades of diesel fuel have the following meaning: Л – summer-grade fuel, З – winter-grade fuel; А – Arctic-grade fuel, and Д – diesel fuel. Where Arctic-grade fuel is not available, use may be made of a blend of winter-grade fuel with up to 50% kerosene. The grade of diesel fuel used must be correct for the season, because the viscosity of the fuel is strongly affected by the ambient temperature. Too high a viscosity decreases the flowability of the fuel and makes it more difficult to atomize, while a viscosity lower than specified reduces the effectiveness of the fuel as a lubricant and accelerates wear of injection components.

Good diesel fuel should be easy to atomize, should have proper volatility and adequate chemical stability in storage, should not cause corrosion of metals, and should be free from water and mechanical impurities.

The fuel system of a diesel engine includes such units as the fuel injection pump and fuel injectors whose movable parts are assembled to have very small clearances – a human hair is tens of times as thick by comparison – and so, the ingress of mechanical impurities into the system will quickly ruin these delicate components. Therefore, only clean fuel must be used to fill the fuel tank of the tractor or truck. Sufficient time (not less than 48 hours) should be allowed for any foreign matter which might be present in the fuel to settle to the bottom of the storage tank before filling the fuel tank of the tractor or truck. The fuel storage tanks must be clean, free from rust and scale. Their filler necks must be kept closed. If a dispensing pump or a siphon hose is used to transfer fuel from the storage tank to the tractor or truck, make certain that the pump intake pipe or the intake portion of the hose is 8 cm above the tank bottom. If a container and a funnel are used to transfer fuel from the storage tank to the tractor or truck, keep the container and the funnel clean by using a cover or by flushing them with a small quantity of fuel prior to use. The funnel should be provided with a metal

screen. Prior to use, the funnel screen should be covered with two or three layers of a silk or flannel cloth, pile upwards, rinsed in clean fuel beforehand.

Take care to prevent water from getting into the fuel tank of your tractor or truck, because it may cause corrosion and adversely affect all moving parts of the fuel injection system, especially the injector nozzles. Water droplets will not pass through the multihole nozzles, therefore, they may be damaged.

The capacity of the fuel tank is sufficient for the tractor to run under full load during a shift and a half. Fill the tank at the end of each shift's operation to keep it as full as possible at all times. This will help to minimize the surging of the fuel, reduce corrosion of the tank walls, and prevent moisture from condensing in the tank.

Prior to filling the fuel tank, wipe clean the filler neck and cap, clean out the vent hole in the cap, and rinse the filler neck screen filter in clean fuel.

Do not fail to observe fire-prevention rules when handling any type of automotive fuel.

8.2. Air Cleaner and Turbocharger

AIR CLEANERS. It will be recalled that air is a mixture of a large number of gases – oxygen, nitrogen, hydrogen, etc., oxygen needed for the combustion of fuel accounting for around 23% of the total mass of dry air.

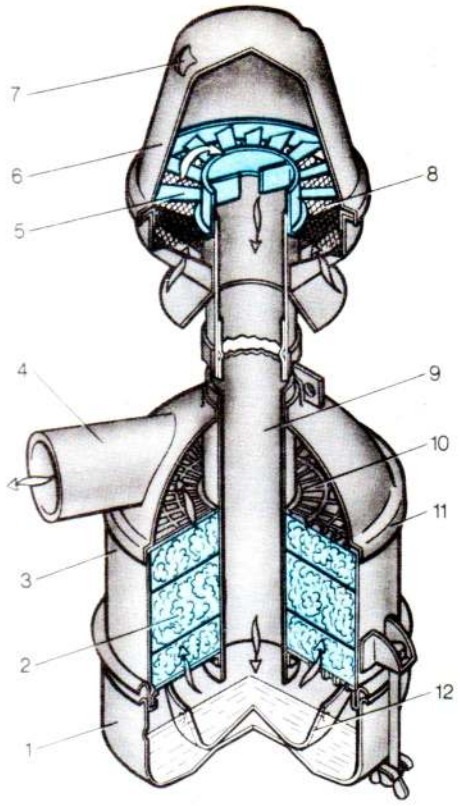
The air surrounding an operating tractor contains a large amount of dust. For example, when operating tillage machines in dry weather, the dust content of the ambient air comes to 2.5 g/m^3, reaching 6 g/m^3 in desert conditions. Road dust is made up of oxides of calcium, iron, silicon, and other substances. The surface hardness of silica (quartz) particles – the major constituent of dust – is two times that of high-quality steels. In one hour of operation, a medium-power tractor engine inhales around 200 m^3 of air. If the air were not cleaned, several kilograms of dust could get into the engine cylinders during a shift. Hard dust particles accelerate wear of the cylinders, pistons, and other rubbing components of the engine. Therefore, it is impermissible to operate a tractor or automobile without cleaning the air entering the engine cylinders.

Modern automotive engines mostly use combination air cleaners utilizing the inertia (centrifugal), viscous impingement, and filtration methods of cleaning. Such air cleaners may be of the two- and three-stage varieties.

Figure 46 shows the most common THREE-STAGE AIR CLEANER used on tractor engines. Its first stage is a centrifugal precleaner, the second stage is an oil-bath filter, and the third stage is an oil-wetted (viscous impingement) filter incorporating several filter elements.

The air cleaner together with the clean air outlet connection is held to the engine cylinder block by means of a bracket and straps. The cleaner consists of body *3* and head piece *11* with stand-up tube *9* welded to it. Clamped to the top end of the stand-up tube is centrifugal precleaner cap *6*. The air cleaner body houses three filter elements *2* of polycaprolactam fiber wadding. Bolted to the air cleaner body from below is oil bath *1*.

The air cleaner operates as follows. The depression produced in the engine intake manifold on the intake stroke makes the ambient air enter the precleaner cap through wire mesh screen *8* and swirler *5* whose inclined vanes set the air in circular motion. The coarser dust particles entering the precleaner together with the air are thrown by centrifugal forces to the walls of the precleaner cap and fall out of it through two windows *7*. In this way, two-thirds of the dust contained in the incoming air are separated in the centrifugal precleaner. From the precleaner the air carrying the finer dust particles passes with a high velocity down the stand-up tube and undergoes a sudden reversal in its direction of flow and velocity against the surface of the oil contained in the oil bath. This causes the heavier dust particles to separate from the air, by virtue of their greater inertia or reluctance to change direction of motion, so that they accumulate in the oil bath. The air then passes upwards through filter elements *2*. Since these become oil-wetted by the oil mist from the air flow, they retain the lighter dust particles by the process of viscous



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Three-stage air cleaner of the Д-240 Model engine

1 – oil bath;
2 – filter elements (of polycaprolactam fiber wadding);
3 – body;
4 – clean air 'outlet' connection;
5 – swirler;
6 – centrifugal precleaner cap;
7 – dust outlet window;
8 – wire mesh screen;
9 – stand-up tube;
10 – filter element cartridge;
11 – head piece;
12 – oil baffle and air deflector

impingement, in which the particles adhere to the viscous surfaces of the filter elements. In the filter elements, the oil mist is reduced continuously until clean oil-free air leaves the filter through outlet connection *4* to flow to the engine cylinders.

Tractor engines also use CYCLONE-TYPE AIR CLEANERS (Fig. 47*a*). These include two cleaning stages – a centrifugal (cyclone) filter stage and a viscous impingement filter stage.

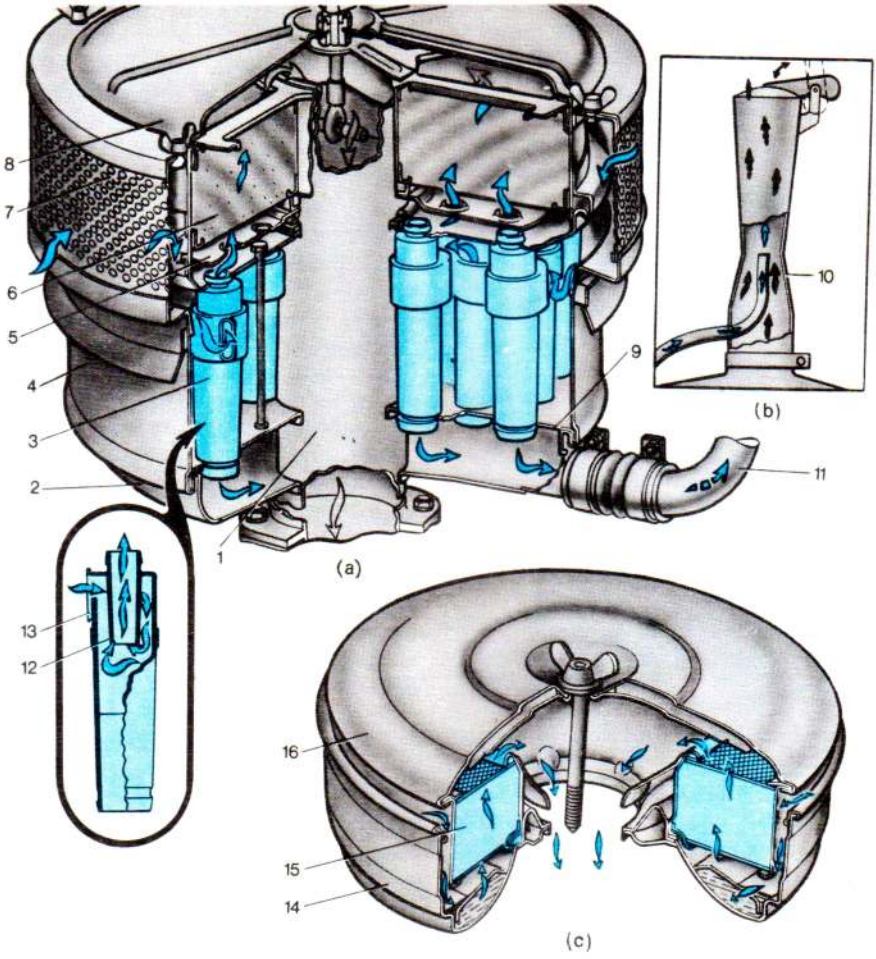
The centrifugal-stage cartridge comprises a series of plastic cyclones *3* pressed in upper and lower pans *9* that are clamped together by bolts. The cartridge is placed in air cleaner housing *4* so that its lower pan rests above dust cup *2* which is connected to ejector tube *10* in the exhaust pipe of the engine by dust removal pipe *11*. Passing through the centers of the dust cup and both pans of the cartridge is stand-up tube *1* which conveys clean air to the engine cylinders. The central tube, dust cup, and air cleaner housing form a rigid one-piece unit. A felt sealing ring is used between the stand-up tube and the upper pan of the cartridge.

On top of the stand-up tube, there is cover *8*. Placed between the cover and the air cleaner housing is wire mesh screen *7* which retains coarse vegetable particles contained in the ambient air. The viscous impingement filter elements of polyurethane are placed under the cover.

Each cyclone *3* is a tube which tapers off at the bottom and is provided with air director sleeve *12* at the top. Welded to the top end of the cyclone tube is inlet fitting *13* which is tangent to the inside surface of the tube.

Before entering the engine cylinders, the ambient air passes through protective screen *7* into cyclones *3* whose intake fittings make the air swirl. Under the action of centrifugal forces, the heavier dust particles contained in the incoming air are thrown outwards against the walls of the cyclone tubes and then drop downward into the dust cup, whence they are sucked out and ejected together with the exhaust gases to the atmosphere, thanks to the depression produced by the ejector device.

The partly cleaned air, i.e., the center of the rotating air mass in the cyclone, passes upward through the air director sleeve into the second cleaning stage of the air cleaner. The oil-wetted filter element of this stage retains the finest dust particles, and the cleaned air thence goes to the engine cylinders through stand-up tube *1*.



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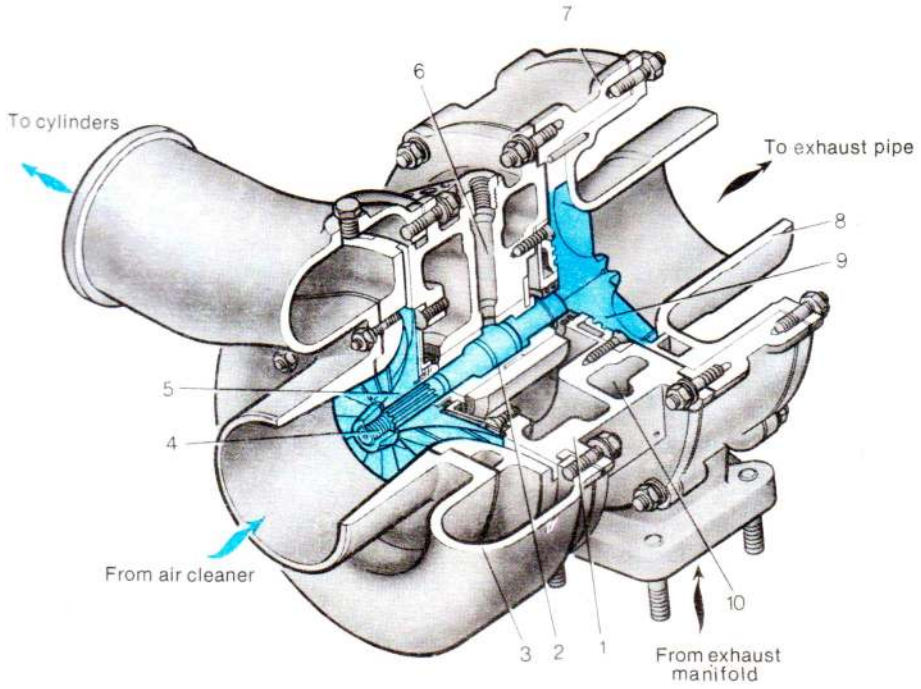
Two-stage air cleaner

(a) cyclone-type air cleaner (T-150K Model tractor); (b) illustrating the process of dust removal; (c) automobile air cleaner (ГАЗ-53А Model truck); 1 – stand-up tube; 2 – dust cup; 3 – cyclone; 4 – housing; 5 – air deflector plate; 6 – filter element cartridge; 7 – protective mesh screen; 8 – cover; 9 – pan; 10 – ejector tube; 11 – dust removal pipe; 12 – air director sleeve; 13 – inlet fitting; 14 – air filter housing; 15 – filter element; 16 – cover

(Fig. 47*c*), usually referred to as the air filter, consists of housing *14* and filter element *15*. The filter element and the air filter cover are assembled to form a one-piece unit. The filter element is stuffed with chopped polycaprolactam fiber 0.2 to 0.3 mm in diameter. Stamped in the bottom of the air filter housing is a shallow pan which is filled with motor oil to form an oil bath. A rubber sealing gasket is used between the filter element housing and the air filter housing.

During engine operation, the ambient air is drawn in the annular space between air filter housing *14* and the housing of filter element *15*.



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Turbocharger

1 – central housing;
2 – bushing;
3 – compressor housing;
4 – shaft;
5 – compressor impeller;
6 – oil passage;
7 – turbine housing;
8 – turbine extension;
9 – turbine wheel;
10 – water jacket

After passing down this vertical annular channel, the air suddenly reverses its direction of flow against the surface of the oil contained in the bath. The heavier dust particles continue to move downwards by inertia, get into the oil, and settle onto the bottom of the oil bath, while the partially cleaned air passes upwards into the filter element where the lighter particles are removed and thence goes to the engine cylinders.

TURBOCHARGER. The power output of a diesel engine of a given displacement can be augmented by supercharging the engine, i. e., by supplying the engine cylinders with compressed air. If more air is delivered to the cylinders, the fuel charge can also be increased, and it will burn completely and will release more energy. The turbocharger (Fig. 48) is an exhaust-gas-driven turbo-compressor used to supply air under pressure to the cylinders of the engine.

The turbocharger consists of a centrifugal compressor with impeller *5* and a gas turbine with wheel *9*, the compressor impeller and the turbine wheel being rigidly fixed on common shaft *4*.

The exhaust gases leaving the engine exhaust manifold enter the gas turbine housing and are directed on the vanes of turbine wheel *9*. The gases force the turbine wheel to rotate together with shaft *4* and then discharge through the exhaust pipe to the atmosphere. Compressor impeller *5* that is held to the shaft draws air from the atmosphere and delivers it at a gauge pressure of 0.05 to 0.06 MPa to the intake manifold and thence to the engine cylinders, thus improving the volumetric efficiency of the engine.

The turbocharger shaft speed is very high (around 40 000 rpm), therefore, even a slight

unbalance of either the turbine wheel or the compressor impeller may cause severe vibration. For this reason, the turbocharger shaft is supported by bronze bearing *2* of the floating sleeve type. The oil to lubricate the bearing is supplied under pressure through a special edge filter. The bearing sleeve has a drilling through which the oil is fed inside the sleeve to lubricate the turbocharger shaft bearing journal. Machined in the outside surface of the bearing sleeve is an annular groove through which the oil is forced into the clearance between the turbocharger housing and the sleeve to form an oil cushion which damps the vibrations caused by the rotating turbocharger shaft. The oil leaving the turbocharger drains into the engine crankcase. The pressure of the oil supplied to the turbocharger is monitored by means of a pressure gauge, for which purpose the central housing of the turbocharger is provided with a special connection fitting. The normal oil pressure downstream of the turbocharger oil filter should be from 0.2 to 0.4 MPa.

The component parts of the turbocharger are cooled by water in jacket *10* that communicates with the cooling system of the engine.

8.3. Fuel Tanks and Filters

FUEL TANKS. The fuel needed for the operation of the tractor or automobile is stored in the fuel tank. Some tractors and automobiles are equipped with an auxiliary fuel tank in addition to the main one.

Fuel tank *9* (see Fig. 45) consists of two halves that are stamped from sheet steel and welded together. Welded inside the tank are two baffles that impart the necessary rigidity to the tank and, at the same time, minimize any violent surging of the fuel content during acceleration, braking, and cornering. The baffles are provided with openings in their lower part to effect communication between the tank compartments formed by them.

Welded in the top part of the fuel tank is a filler pipe whose neck is provided with a removable filter of steel-backed fine mesh brass wire gauze. The fuel level in the tank is checked by means of a fuel measuring rod or dip tube. The tank filler neck is closed by a cap with a hole in it to vent the tank interior to the atmosphere, so that air can enter and take the place of the fuel pumped from the tank. In the absence of suitable venting, a depression would be created in the tank that would not only interfere with the normal fuel delivery, but also tend to cause collapse of the tank. Therefore, the vent hole in the fuel tank filler cap should be always kept clean. To prevent dust from entering the tank together with air, the filler cap is stuffed with metal wool. The joint between the filler cap and the filler neck of the fuel tank is reliably sealed by a cork gasket clamped to the cap by a bolt and steel washers.

Welded in the bottom part of tractor fuel tanks are connection adapters for drain cock *11* and shut-off cock *10*. The shut-off cock serves to disconnect the fuel tank from the fuel system and the drain cock, to draw off water and sediments accumulating in the tank. The outlet side of the shut-off cock is connected to the primary fuel filter by a metal fuel pipe which in tractors of the more recent designs is replaced by a PVC pipe.

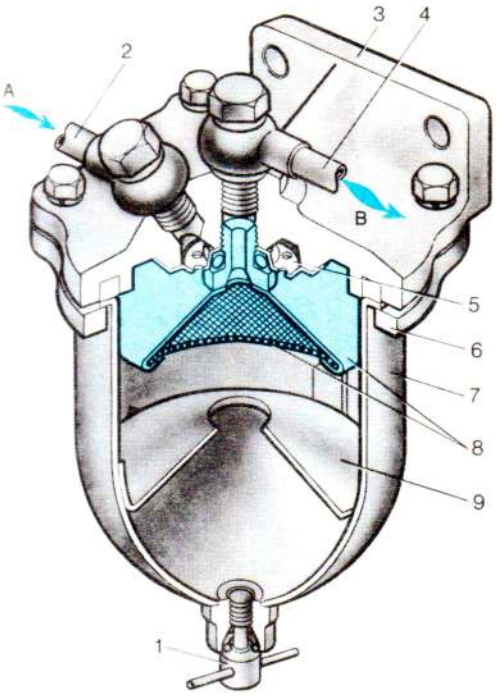
In the upper part of the main fuel tank, there is float-type fuel level sender *7*.

FUEL FILTERS. Automotive engines usually use two fuel filters – a primary fuel filter and a secondary fuel filter – operating in series.

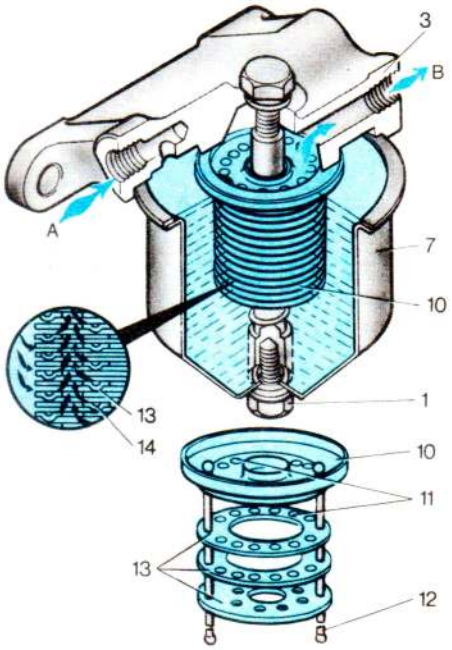
The primary fuel filter cleans the fuel from coarse mechanical impurities.

The tractor PRIMARY FUEL FILTER (Fig. 49*a*) has screen-type filter element *8* consisting of a deflector and a brass wire gauze 0.09 mm in mesh size. The filter element is mounted on a threaded bushing which is screwed in filter body *3* and presses against it fuel distributor plate *5* having eight holes equally spaced around its circumference.

The filter element is placed inside bowl 7 that is secured to the filter body by pressure ring *6* and bolts. The joint between the filter body and bowl is sealed by a gasket of rubberized asbestos fabric. In the lower part of the bowl, there is baffle plate *9*. Screwed in a threaded adapter in the bottom of the filter bowl is drain plug *1*.



(a)



(b)

49

Primary fuel filters

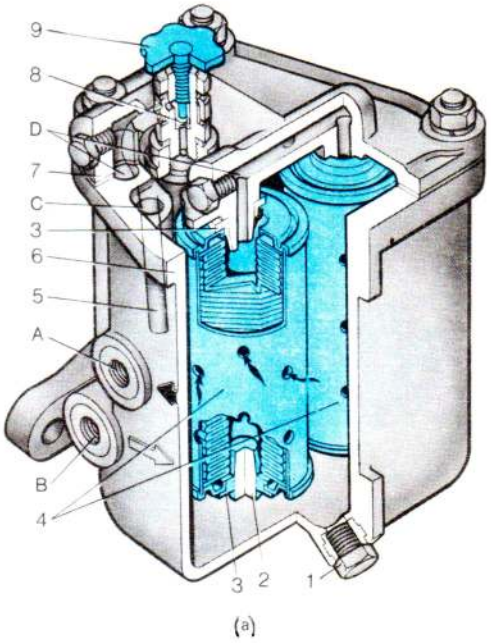
(a) tractor;
(b) automobile;
1 – drain plug;
2 – fuel inlet pipe;
3 – body;
4 – fuel outlet pipe;
5 – fuel distributor plate;
6 – pressure ring;
7 – bowl;
8 – screen-type filter element;
9 – baffle plate;
10 – plate filter element;
11 – holes;
12 – pin;
13 – plates;
14 – lug;
A – fuel in;
B – clean fuel out

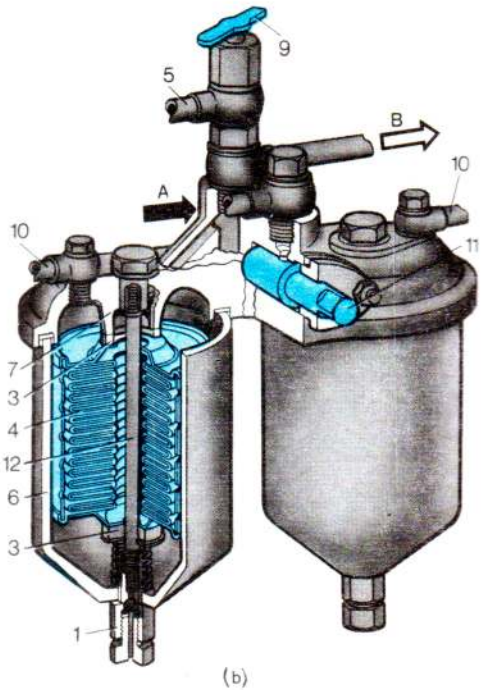
During engine operation, the fuel enters the filter through pipe *2* and the holes in fuel distributor plate *5* and then flows down the annular space between the filter element deflector and the walls of the filter bowl. Some of the fuel gets by inertia under the baffle plate where the coarse foreign particles and water contained in the fuel settle out. The fuel then passes upward through the central hole in the baffle plate into the filter element whose gauze retains fine mechanical impurities and then leaves the filter through the central hole in the filter body and fuel outlet pipe *4*.

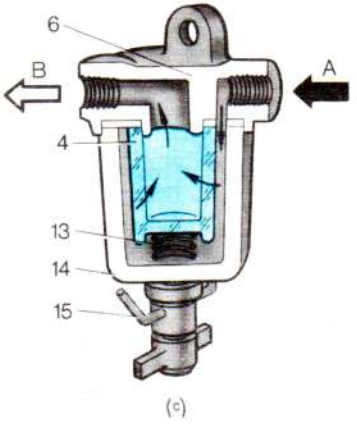
The filter element of the automobile primary fuel filter (Fig. 49*b*) comprises a set of aluminum plates *13* 0.15 mm in thickness. The plates are made with 0.05-mm high lugs *14*, holes *11* for the passage of fuel, and two holes to fit locating pins *12*.

In operation, the fuel enters filter bowl *7* through the inlet hole. Since the fuel flow velocity in the bowl sharply drops by comparison with that in the fuel pipelines, the water and coarse mechanical impurities contained in the fuel have enough time to settle to the bottom. Drain plug *1* serves to periodically draw off water and sediment. Then the fuel passes through the clearances between the plates of the filter element, where particles coarser than 0.05 mm across are retained, and leaves the filter through the holes in the plates and the fuel outlet hole in the filter body.

SECONDARY FUEL FILTER cleans the fuel from







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Secondary fuel filters

(a) tractor (MT3-80 Model tractor); (b) two-stage tractor (ДТ-75M Model tractor); (c) automobile; 1 – drain plug; 2 – support pin; 3 – rubber seal; 4 – filter element; 5 – air bleed tube; 6 – housing; 7 – cover; 8 – shut-off ball; 9 – air bleed valve; 10 – leak-off pipe from fuel injectors; 11 – cock; 12 – clamping bolt; 13 – spring; 14 – sediment bowl; 15 – retaining yoke; A – fuel in; B – clean fuel out; C – contaminated fuel duct; D – clean fuel duct

the finest mechanical impurities and water. The tractor secondary fuel filter (Fig. 50*a*) usually has several filter elements accommodated in filter housing *6*. In the bottom of the housing, there is a hole closed by drain plug *1* for drawing off water and sediment.

Filter elements *4* are cylindrical cardboard cartridges containing special filter paper folded in the form of a polyhedral helical bellows. The cartridges are provided with holes for the passage of fuel and are closed from both ends by tin-plate covers. Rubber sealing rings are used at the top and bottom of the filter elements. The elements are one-piece,

disposable units. Each of them is mounted on a support pin in the filter housing. The filter housing is closed by cover 7 on top of which there is air bleed valve 9.

All the filter elements operate in parallel. The fuel delivered by the fuel transfer pump enters the filter housing through the hole *A* and then passes through the holes in the filter element cartridges and filter paper inside the elements. The fuel cleaned from the minutest foreign particles in the filter elements then goes through the hole *B* to the fuel injection pump by the low-pressure line.

As its name implies, the air bleed valve serves to release the air that has been trapped in the engine fuel system. If the valve handle is turned counterclockwise to open the valve while the fuel transfer pump is operating, the fuel will lift shut-off ball *8* off its seat and flow out of the filter housing through air bleed tube *5*. If air is present in the fuel system, air bubbles will be the first to emerge from the air bleed tube. When the stream of fuel issuing from the air bleed tube becomes even, i.e., free from air bubbles, the handle of the air bleed valve is turned clockwise and the shut-off ball closes the air bleed hole of the filter.

Some tractor engines use two-stage secondary fuel filters (Fig. 50*b*). In these filters, both filter elements operate in series. The second filter element is a check element: it is used to check on the operation of the primary fuel filter and the first filter element of the secondary fuel filter. If excessively contaminated, the first filter element of the secondary fuel filter can be flushed without removing the filter from the engine. For this purpose, the filter cover is provided with a cock that can be set in two positions – the working position and the flushing position. With the cock in the flushing position, the direction of fuel flow in the first stage of the filter is reversed, so that the foreign particles deposited on the external surface of the filter element can be removed. When flushing, the drain plug of the first filter stage must be unscrewed at least two turns. The two-stage secondary fuel filters used on the more powerful tractor engines are additionally equipped with a check filter including a single filter element that is interchangeable with the main filter elements.

The automobile secondary fuel filter (Fig. 50*c*) is set between the fuel pump and carburettor. The filter consists of housing *6*, sediment bowl *14*, and filter element *4*. The filter element may be fabricated of some ceramic material or of fine wire gauze coiled in a roll. During engine operation, some mechanical impurities settle to the bottom of the sediment bowl and the rest are retained by the filter element.

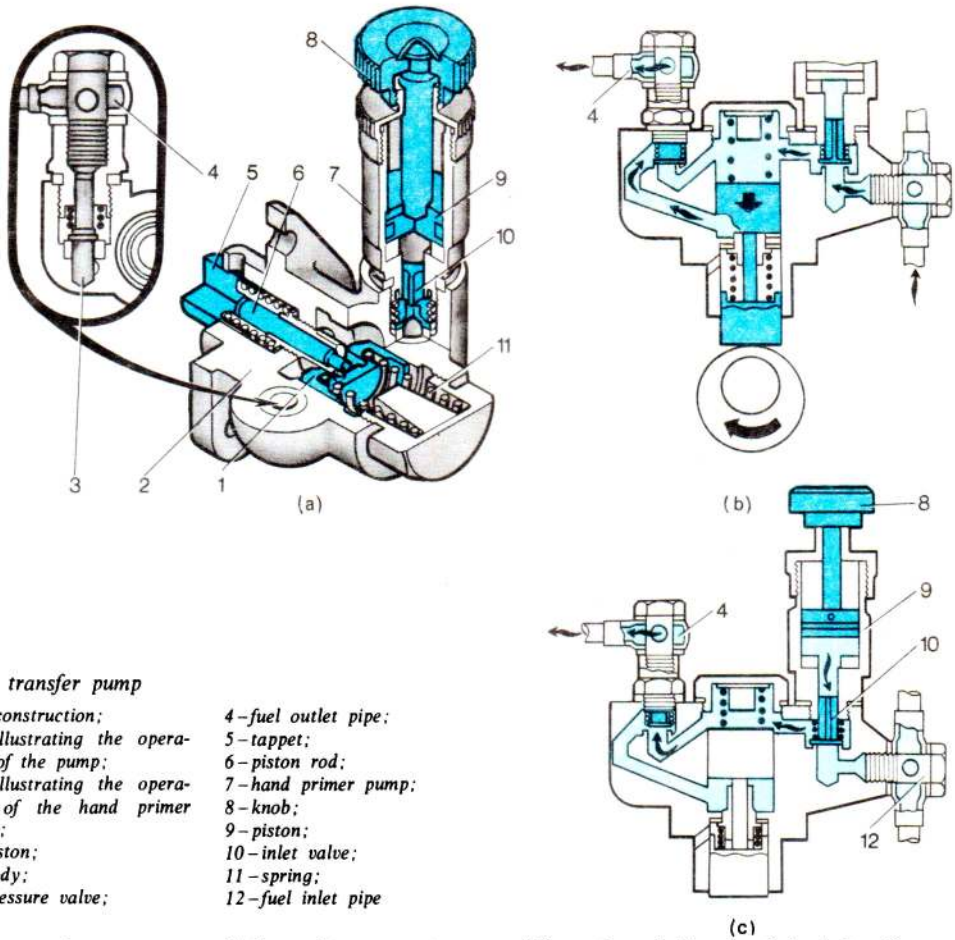
8.4. Fuel Pumps

Fuel pumps serve to deliver fuel either to the carburettor (in automobile engines) or to the fuel injection pump (in tractor engines). In the latter case, such pumps are usually referred to as the fuel transfer pumps.

THE FUEL TRANSFER PUMP (Fig. 51) is mounted on the fuel injection pump. Irrespective of the condition of the fuel filters that offer resistance to the flow of fuel, the transfer pump must deliver adequate amount of fuel to the injection pump and maintain a fuel pressure in its manifold in the range 0.08 to 0.12 MPa. All the tractor engines considered in this book use fuel transfer pumps of the piston type. The pump (Fig. 51*a*) consists of body *2* which houses piston *1*, inlet valve *10*, and pressure valve *3*. The valves are tightly pressed against their seats by springs. The piston is free to slide in its carefully machined bore in the transfer pump housing. The piston is acted upon by spring *11* from one side and by rod *6* from the other. The other end of the rod rests against tappet *5*.

The tappet is provided with a roller and is spring-loaded against an eccentric carried on the injection pump camshaft.

It takes two piston strokes for the transfer pump to deliver fuel to the injection pump. As the injection pump camshaft rotates, the eccentric lobe moves away from the tappet roller and spring *11* forces the piston to move downward (Fig. 51*b*). The fuel contained in the space below the piston is thus forced to flow through the outlet pipe and secondary fuel filter to the fuel injection pump. At the same time, the



51

Fuel transfer pump

(a) construction;
(b) illustrating the operation of the pump;
(c) illustrating the operation of the hand primer pump;
1 – piston;
2 – body;
3 – pressure valve;
4 – fuel outlet pipe;
5 – tappet;
6 – piston rod;
7 – hand primer pump;
8 – knob;
9 – piston;
10 – inlet valve;
11 – spring;
12 – fuel inlet pipe

downward movement of the piston creates a depression in the space above the piston, which causes the fuel to be drawn in the transfer pump from the fuel tank through the open inlet valve *10* and the primary fuel filter.

As the injection pump camshaft continues to rotate, the eccentric lobe lifts the tappet together with piston *1* against the resistance offered by spring *11*. A depression is produced in the space below the piston, while the fuel pressure in the space above the piston is increased. This pressure causes inlet valve *10* to close and pressure valve *3* to open, and the fuel is expelled from the space above the piston into the one below it. This piston stroke is supplementary. Then the above sequence of events is repeated.

When the delivery of fuel to the engine cylinders is reduced, the fuel pressure in the space below the piston of the transfer pump is increased and, by offsetting in part the spring pressure on the piston, limits the piston stroke. In this way, the quantity of fuel delivered by the transfer pump to the injection pump is automatically changed in accordance with the engine requirements. The normal delivery of the transfer pump is 1.5 l/min and the delivery pressure, 0.15 MPa.

Mounted on the fuel transfer pump body above the inlet valve is a hand primer pump consisting of a cylinder, piston *9*, and a piston rod with knob *8*. This pump is used for priming the fuel system and bleeding air from it prior to

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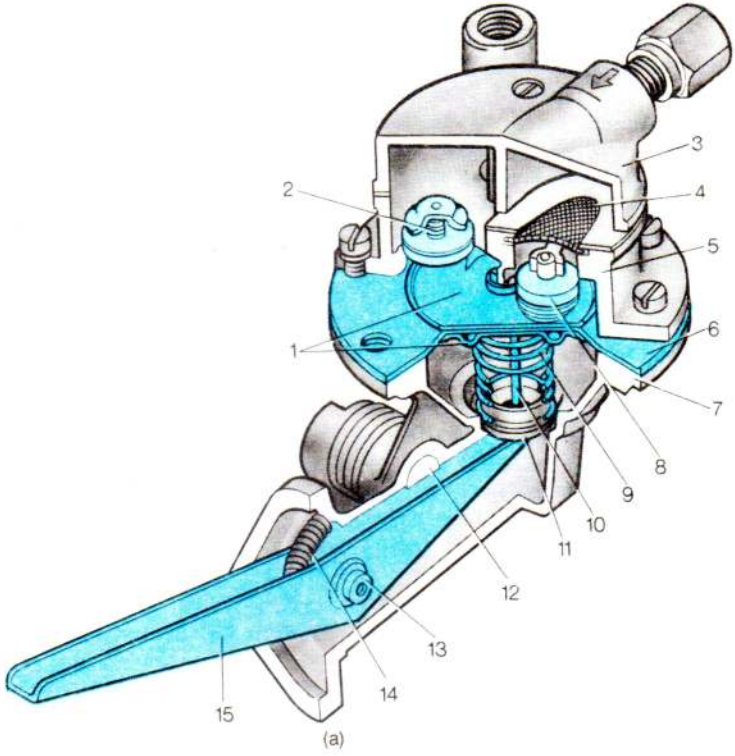
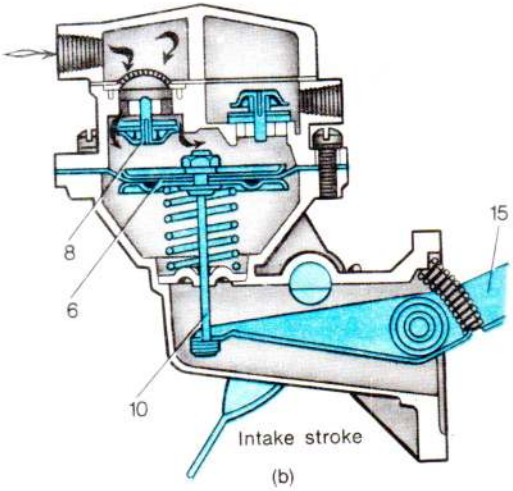
Gasoline pump

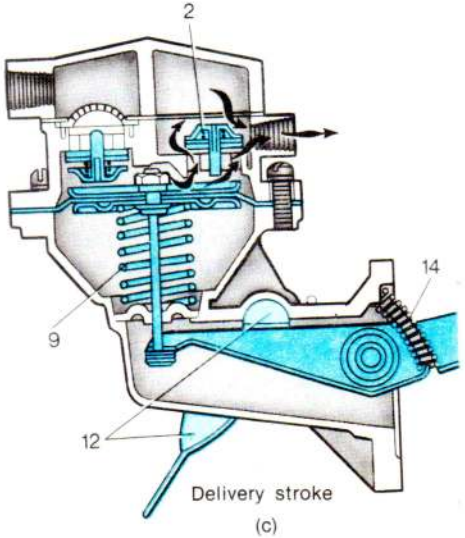
(a) construction;
(b) and (c) illustrating the operation of the pump;
1 – plates;
2 – outlet valve;
3 – cover;
4 – screen filter;
5 – pump head;
6 – diaphragm;
7 – pump body;
8 – inlet valve;
9 – pressure (diaphragm return) spring;
10 – spindle;
11 – seal;
12 – hand priming lever;
13 – rocker-arm pivot pin;
14 – rocker-arm return spring;
15 – rocker arm



(a)



(b)



(c)

starting the engine. Before priming the fuel system, it is necessary to open the air bleed valve of the secondary fuel filter. When pulling on the primer pump knob, the piston is moved upward. This creates a vacuum in the space below the piston, so that inlet valve *10* opens and the fuel fills the space. Pushing on the primer pump knob (Fig. 51*c*) compresses the fuel in the pump cylinder, so that the inlet valve closes and pressure valve *3* opens to let the fuel flow through the outlet pipe of the transfer pump to the secondary fuel filter. After fuel system has been freed from air, the primer pump knob is depressed all the way down and screwed on the pump cylinder cover as far as it will go to avoid air being sucked in the system.

The automobile fuel pump, commonly called THE GASOLINE PUMP (Fig. 52*a*), is of the diaphragm type. It consists of body *7*, cover *3*, and head *5*. The pump body accommodates pivoted rocker arm *15* with its return spring *14* and hand priming lever *12*. Sandwiched between the pump body and head is flexible diaphragm *6* made of varnished or rubberized cloth. Plates *1* connect the diaphragm to spindle *10* whose lower end is linked with the inner end of the rocker arm. Under the diaphragm, there is pressure (diaphragm return) spring *9*.

Head *5* of the gasoline pump is partitioned to form two compartments – an inlet compartment and an outlet compartment. The outlet compartment houses outlet valve *2* and the inlet one, two inlet valves *8* covered by a screen filter. The head is bolted to the pump body, and the pump cover is bolted to the head.

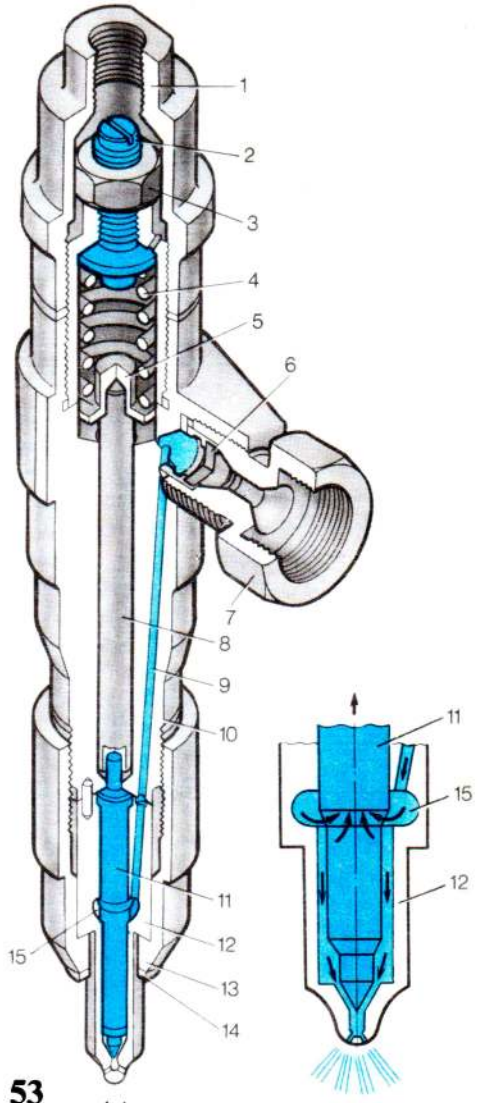
The gasoline pump is driven from an eccentric, or a special fuel-pump lobe, on the engine camshaft. As the camshaft rotates, the eccentric pushes up against the outer end of rocker arm *15* (Fig. 52*b*), forcing the arm to pivot on its pin. When one end of the rocker arm is pushed up, the other end of the arm pulls down on spindle *10* together with plates *1*, making the diaphragm deflect downwards against the resistance offered by the pressure spring. This action creates a vacuum in the gasoline chamber above the diaphragm, which opens inlet valves *8* and makes gasoline flow from the fuel tank through the fuel line and screen filter in the pump inlet compartment, past the inlet valves, and into the gasoline chamber. Then the lobe moves away from the rocker arm to allow the outer end of the arm to move down and release the diaphragm. Now pressure spring *9* (Fig. 52*c*) takes over and pushes the diaphragm up, producing pressure in the gasoline chamber. This pressure closes the inlet valves and opens outlet valve *2* and then forces the gasoline out of the gasoline chamber. The gasoline flows past the outlet valve and then through the fuel line to the carburettor.

The gasoline pump is designed to have its delivery adequate to the maximum fuel flow through the carburettor. To fill the carburettor float chamber with fuel when the engine is stopped, use is made of hand priming lever *12* arranged on a side wall of the gasoline pump body. The lever has a return spring and pivots on a spindle whose end is partly cut to form a flat. With the return spring holding the lever in the neutral position, the flat on the end of the spindle is disposed parallel with and above the inner end of the rocker arm, so that it does not interfere with the normal operation of the gasoline pump. But pulling on the hand priming lever causes the edge of the flattened end of its spindle to depress the inner end of the rocker arm, pulling down the diaphragm.

If the diaphragm is in its lowermost position when the engine is stopped, then to enable one to fill the carburettor float chamber with the aid of the hand priming lever, the engine crankshaft should be turned 360° with a crank handle to make the eccentric move from under the rocker arm.

8.5. Fuel Injectors and Fuel Lines

The function of the fuel injector (Fig. 53) is to deliver finely atomized fuel under high pressure to the combustion chamber of the engine. Modern tractor engines use fuel injectors with multihole nozzles 0.32 mm in spray hole diameter. All component parts of the injector are carried in nozzle holder *10*. The main part of the injector is the nozzle comprising nozzle body *12* and nozzle needle valve *11*. The nozzle



53

Fuel injector

(a) construction;
(b) illustrating the operation of the injector;
1 – cap nut;
2 – adjusting screw;
3 – lock nut;
4 – spring;
5 – spring seat;
6 – screen filter;
7 – inlet fitting;
8 – spindle;
9 – fuel passage;
10 – nozzle holder;
11 – nozzle needle valve;
12 – nozzle body;
13 – nozzle cap nut;
14 – washer;
15 – nozzle pressure chamber (gallery)

body and needle valve are fabricated from alloy steel. They are thoroughly machined and have high surface hardness necessary for operation in conditions of high temperatures and elevated pressures. The bore in the nozzle body and the nozzle needle valve are lapped to a close tolerance and are a matched set, so that neither the nozzle body nor the needle valve may be replaced individually. The needle valve is pressed against a conical seat in the nozzle body by spring *4* acting through the intermediary of stem *8*. The spring pressure, hence injection pressure, is adjusted by adjusting screw *2*. The adjusting screw is screwed in the bottom of the injector spring cap nut which in turn is screwed in the nozzle holder. Lock nut *3* is used to prevent the adjusting screw from unscrewing spontaneously. The screw is covered by nozzle holder cap nut *1* provided with a threaded hole to connect the leak-off pipe through which the leak-off fuel (used to lubricate the nozzle valve) filling the pressure spring and adjusting screw area is returned to the fuel tank or the secondary fuel filter.

In operation, fuel from the injection pump enters pressure chamber (gallery) *15* in the nozzle body through supply passage *9* and a high-pressure pipe. When the fuel pressure in the pressure chamber becomes so high that the force acting on the pressure taper of the needle valve from below exceeds the set spring force on the stem, the needle valve lifts off its seat and comes to rest with its upper shoulder against the face of the nozzle holder. Fuel is then forced out of the nozzle spray holes into the combustion chamber in a spray pattern which depends on the type of nozzle used.

After the injection of fuel has been ended, the fuel delivery from the injection pump ceases, the pressure in pressure chamber *15* of the nozzle drops instantly, and the pressure spring snaps the needle valve onto its seat, preventing unpressurized fuel from leaving the nozzle.

The fuel injector is installed in a brass injector tube, or sleeve, which is fitted in a hole in the cylinder head, and is held in place by a special clamp.

Low-pressure fuel lines use brass pipes or

thin-walled steel pipes provided with a corrosion-resistant coating. Some engines make use of PVC tubing for the purpose.

High-pressure fuel lines connecting the fuel-injection pump with the injectors are steel pipes 2 mm in inside diameter and 7 mm in outside diameter. The external surfaces of the pipes are oxidized for corrosion protection. The ends of the pipes are upset in a special device to form tapered male seats for connecting the pipes to the fuel-injection pump discharge and injector inlet fittings. The pipes should be fitted well to their respective fittings, so that the union nuts may be screwed on the fittings by hand. The nuts are finally tightened with a wrench.

Before installing them on the engine, all fuel pipes should be thoroughly washed in diesel fuel and then blown through with compressed air.

8.6. Multi-Element Fuel-Injection Pump

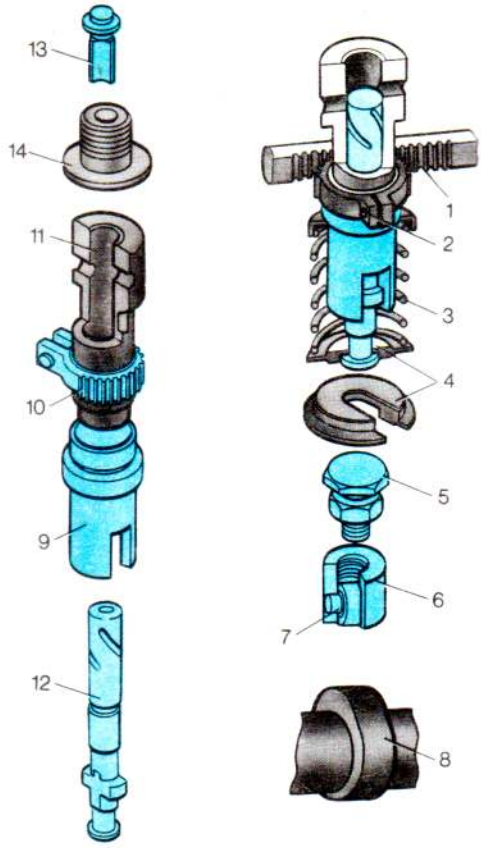
The fuel-injection pump serves the purpose of delivering, under high pressure, accurately timed and metered quantities of fuel to each cylinder of an engine, in accordance with the engine speed and load.

Tractor engines may use both multi-element and distributor-type fuel-injection pumps.

The multi-element pump comprises an in-line arrangement of single-acting plunger pumps (pumping elements), one being provided for each fuel injector. Let us consider the construction and operation of a pumping element of a typical multi-element fuel-injection pump.

THE PUMPING ELEMENT (Fig. 54) consists of a plunger-and-barrel assembly, spring *3*, a roller tappet, cam *8* of the injection pump camshaft, and delivery valve *13* with its body *14*.

The plunger-and-barrel assembly is the heart of the pumping element. It comprises plunger *12* reciprocating in close-fitting barrel *11*. The plunger and the barrel are fabricated from alloy steel and heat treated to have a high hardness, for they must withstand high fuel pressures during operation. On the delivery stroke of the plunger, the fuel must lubricate the rubbing surfaces of the pumping element, but, at the same time, it must not leak past the plunger from the upper to the lower side of the barrel. Therefore, these parts are lapped together in pairs to a very close tolerance (0.001 to



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Pumping element of a fuel-injection pump

1 – control (fuel) rack;
2 – gear-segment screw;
3 – plunger spring;
4 – lower spring seat;
5 – tappet adjusting bolt;
6 – tappet shell;
7 – tappet roller;
8 – cam;
9 – control sleeve;
10 – gear segment;
11 – barrel;
12 – plunger;
13 – delivery valve;
14 – delivery-valve body

0.002 mm) and must not be replaced individually.

The fuel-injection pump barrel is a cylinder with somewhat thickened upper portion. In the thickened part of the barrel, there are two opposite side openings located at different heights. The upper opening – the inlet port – serves to fill the barrel space above the plunger with fuel. The lower opening – the spill port – is used to by-pass fuel to the inlet side of the pump. When the barrel is mounted in the pump housing, both ports are open to the U-shaped fuel manifold of the pump.

The upper part of the plunger has a center- and a cross-drilled hole and a fuel cut-off (spill) spiral groove, called the helix, the center-drilled hole and the helix communicating with each other via the cross-drilled hole. The helix makes it possible to vary the delivery of the fuel-injection pump without changing the actual stroke of the pump plunger. An annular groove in the center part of the plunger serves for uniform distribution of fuel over the barrel face, the fuel in this case playing the part of lubricating oil.

On the lower part of the plunger, there are two flanges and a circular recess. The flanges slide in the slots of control sleeve *9* which carries gear segment *10* meshing with the control (fuel) rack of the pump. The circular recess is used for hooking lower seat *4* of the plunger spring to the plunger. The spring serves to return the plunger to its lower position on the intake stroke.

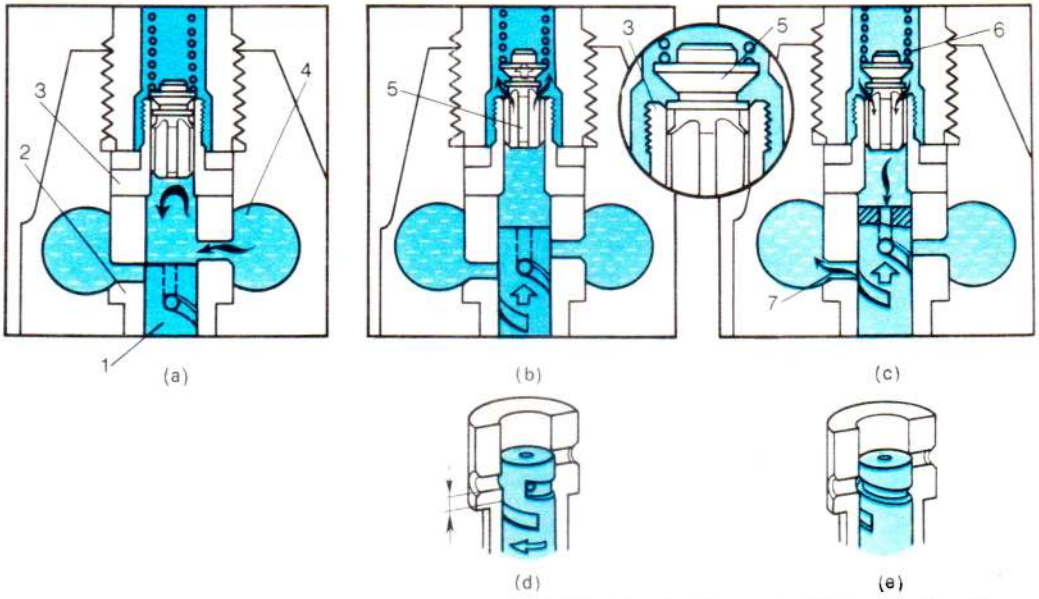
The plunger is lifted by a roller tappet which receives its motion from its own cam on the engine driven camshaft of the fuel-injection pump. The tappet consists of shell *6*, pin mounted roller *7*, and adjusting bolt *5* with a lock nut. To avoid damage to the fuel-injection pump components during operation, the tappets are located in the pump housing by screws that are screwed in the housing opposite the tappets and wired in pairs.

To achieve clean-cut beginning and ending of injection, the barrel is closed at the top by a delivery-valve assembly consisting of spring-loaded delivery valve *13* (through which fuel under pressure is piped to the appropriate fuel injector) and a close-fitting valve body.

Figure 55 illustrates the operation of a pumping element of a fuel-injection pump. The plunger reciprocates in the barrel under the action of the tappet and the plunger spring. As plunger *1* moves down, the fuel under the transfer-pump pressure enters barrel *2* from inlet side *4* of the U-shaped fuel manifold of the pump (Fig. 55*a*). As the plunger moves up, it closes the inlet port of the barrel (Fig. 55*b*) and pressurizes the fuel in the barrel. The fuel pressure in the barrel builds up rapidly, causing delivery valve *5* to lift off its seat and allow the fuel under high pressure to enter the high-pressure injection line leading to the fuel injector. As soon as the edge of the helix uncovers the spill port of the barrel (Fig. 55*c*), the fuel pressure quickly drops while the fuel passes through the passages in the plunger and spill port *7* of the barrel into the U-shaped fuel manifold and thence through a pressure-relief valve to the transfer pump. As this happens, spring *6* makes the delivery valve retract quickly and snap onto its seat, drawing some fuel from the high-pressure injection line in the process. As a result, the pressure in the high-pressure line is suddenly reduced, causing the injector needle valve to snap onto its seat to end the injection of fuel as suddenly. Thus, the pumping period (effective stroke of the plunger) lasts from the moment the upper edge of the plunger ends the closure of the inlet port of the barrel to the moment the edge of the helix commences uncovering the spill port.

The effective stroke of the plunger can be varied by turning the plunger within the barrel so as to change the position of the helix relative to the spill port (Fig. 55*d*). With this plunger design (the so-called lower-helix design), the beginning of delivery is constant, whereas the ending of delivery is variable in accordance with the plunger position in the barrel. The closer the helix edge facing the spill port to the upper edge of the plunger, the sooner the ending of delivery occurs. The shortest distance between the helix edge and the plunger edge corresponds to the no-fuel position of the plunger (Fig. 55*e*).

The delivery of each pumping element is



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Illustrating the operation of a pumping element of a fuel-injection pump

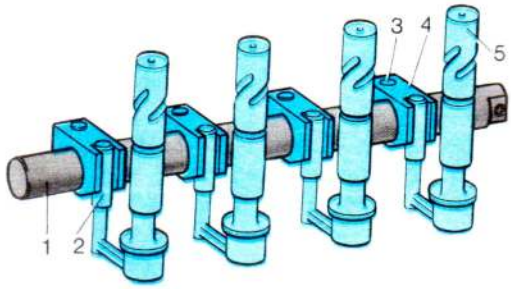
(a) charging the barrel with fuel;
(b) delivering fuel to the injector;
(c) end of fuel delivery (fuel cut-off);
(d) rotating the plunger to increase fuel delivery;
(e) no-fuel position of the plunger;

1 – plunger;
2 – barrel;
3 – delivery-valve body;
4 – inlet side of U-shaped fuel manifold;
5 – delivery valve;
6 – valve spring;
7 – spill port

adjusted by turning control sleeve *9* (see Fig. 54) relative to gear segment *10*, gear-segment screw *2* being loosened beforehand. The fuel charges delivered by all pumping elements of the fuel-injection pump are varied by moving fuel rack *1* which turns simultaneously all plungers *12* about their axes through the medium of gear segments *10* and control sleeves *9*.

Some multi-element fuel-injection pumps use a plunger-rotating (fuel-changing) mechanism with a smooth control rod instead of the fuel rack (Fig. 56). The rod carries control forks *4* which are held to the rod by clamping screws *3*. The slots in the control forks receive plunger arms *2* pressed on the lower ends of the plungers. In such pumps, the delivery of each pumping element is adjusted by moving the appropriate control fork along the control rod, screw *3* being loosened beforehand.

The delivery of the fuel-injection pump is increased by moving the fuel rack forward. The control-rack movement is controlled by



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Plunger-rotating (fuel-changing) mechanism

1 – control rod;
2 – plunger arm;
3 – control-fork clamping screw;
4 – control fork;
5 – plunger

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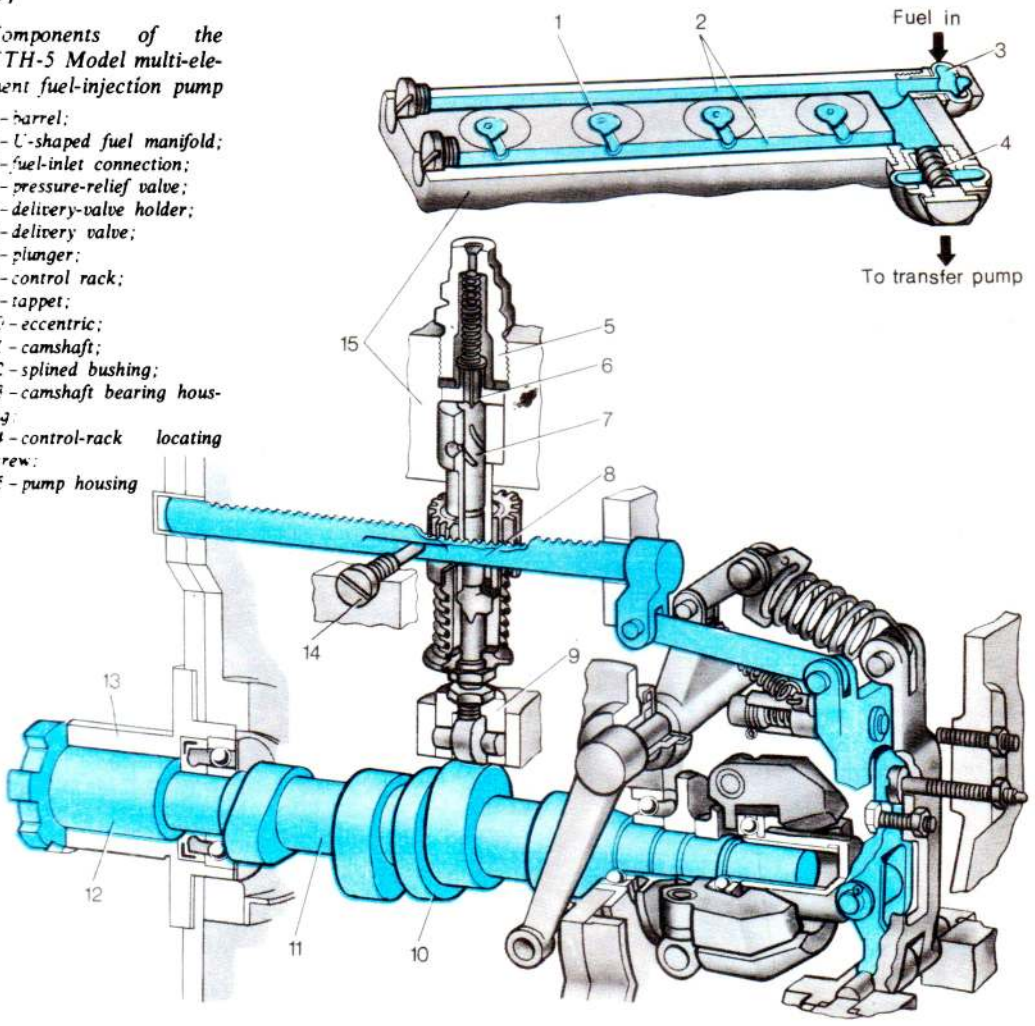
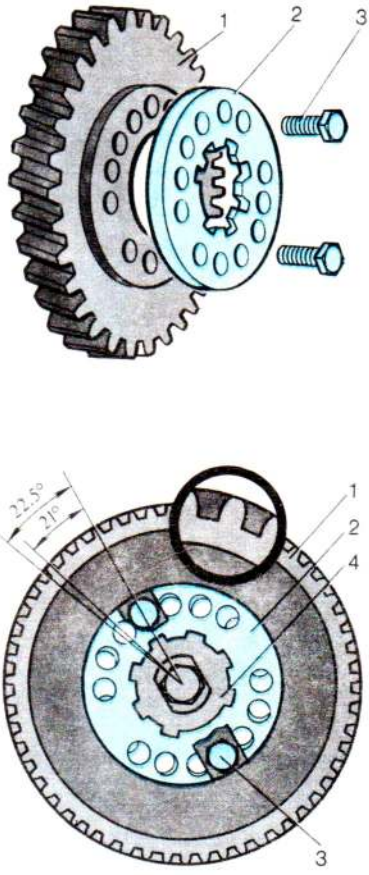
Components of the YTH-5 Model multi-element fuel-injection pump

1 – barrel;
2 – U-shaped fuel manifold;
3 – fuel-inlet connection;
4 – pressure-relief valve;
5 – delivery-valve holder;
6 – delivery valve;
7 – plunger;
8 – control rack;
9 – tappet;
10 – eccentric;
11 – camshaft;
12 – splined bushing;
13 – camshaft bearing housing;
14 – control-rack locating screw;
15 – pump housing



a governor mounted on the rear wall of the pump housing (Fig. 57). The housings of some fuel-injection pump have detachable heads, but in our case, the pump housing is one-piece unit. It is divided by a cast horizontal partition into two parts. In the upper part of the pump housing, there are four vertical bores for mounting the pumping elements and horizontal drillings which form U-shaped fuel manifold *2* of the pump. The manifold is connected by a low-pressure and a by-pass fuel line to the fuel transfer pump. Pressure-relief valve *4* carried in the by-pass line fitting of the injection pump maintains a pressure of around 0.1 MPa in the U-shaped fuel manifold. The walls of the upper part of the pump housing are provided with a small inspection hole to the left and a large mounting hole to the right. Both holes are closed by covers. Fitted in the inspection-hole cover is a breather to vent the pump interior to



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Fuel-injection pump drive

1 – drive gear;
2 – splined washer;
3 – bolt;
4 – splined bushing

the atmosphere. The breather is equipped with a cellular plastic filter to clean the air entering the pump interior from the atmosphere. At the bottom of the pump housing, there is a drain pipe to draw off the excess oil and also fuel that has leaked past the plungers of the pumping elements and the piston of the transfer pump.

Supported by two ball bearings in the lower part of the pump housing is a camshaft that is common to all the pumping elements of the fuel-injection pump. The camshaft carries four cams arranged at 90° to one another. Eccentric *10* for driving the transfer pump is disposed between the second and third cams.

The injection pump camshaft is driven by a drive gear which is connected to the camshaft through the intermediary of splined bushing *12*. The splined bushing is keyed to the camshaft and is linked with drive gear *1* (Fig. 58) by means of splined washer *2* and two bolts *3*. Gear *1* is freely mounted on the extension of the camshaft front bearing housing. Pressed in the central hole of the gear is a bronze bushing whose flange slides over the end face of the bearing housing when the gear is rotating. Washer *2* can be slipped on the splined bushing in a definite position only, thanks to the fact that one spline is missing. This makes it possible to remove the injection pump from the engine and then install it back in place without disturbing the set injection timing.

The injection timing for all the pumping elements of the injection pump is adjusted by changing the position of the splined washer relative to the pump drive gear. For this purpose, the washer is provided with 14 holes spaced 21° apart along a circumference of one and the same radius. In its turn, the drive gear has 14 threaded holes in the front end face of its hub, but the holes here are spaced at 22.5-degree intervals. With such an arrangement of the holes in the splined washer and the drive gear, only two pairs of diametrically opposite holes can be made to match.

If the splined washer is turned clockwise relative to the pump drive gear intil the next two pairs of holes are matched, the beginning of injection will be advanced 3°. If the washer is turned counterclockwise, the injection advance angle will be decreased. During normal operation, each pumping element of the injection pump starts delivering fuel to the appropriate injector several degrees before the piston reaches TDC on the compression stroke. While the beginning of injection for all pumping elements can be changed by changing the position of the splined washer relative to the

pump drive gear, the beginning of injection of each pumping element is changed by means of the tappet adjusting bolt.

8.7. Distributor-Type Fuel-Injection Pump

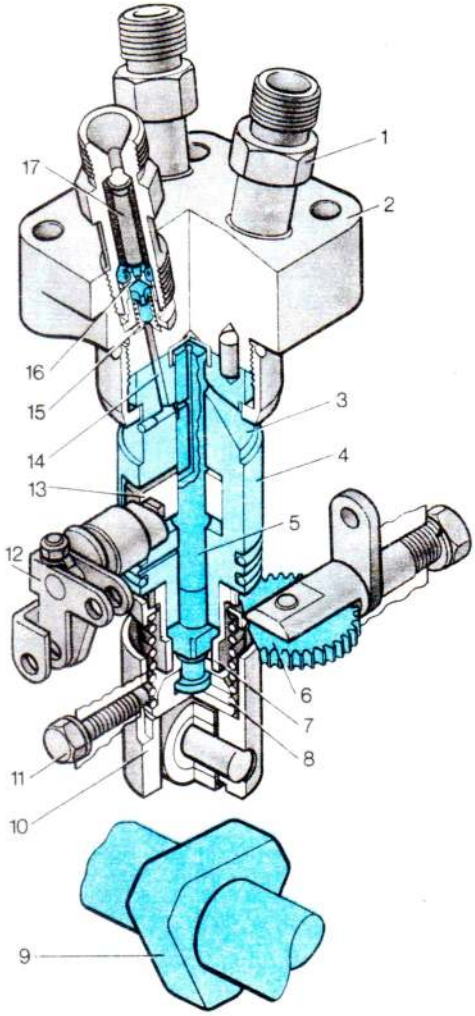
In the distributor-type fuel-injection pump, one plunger-and-barrel assembly delivers fuel not to one cylinder, as is the case with ordinary multi-element pumps, but to several cylinders. Therefore, the plunger here not only reciprocates, but also rotates, distributing fuel to a number of cylinders in turn. If a V-type engine is equipped with a distributor-type fuel-injection pump having two pumping elements (sections), each pumping element is then used to deliver fuel to its own bank of cylinders. The plunger diameter is from 8 to 10 mm, depending on the pump model, and the plunger stroke is 8 mm.

The heart of the pumping element (Fig. 59) is the plunger-and-barrel assembly consisting of plunger *5* which reciprocates as well as rotates in a close-fitting barrel *4* closed at the top by a cap. In the upper part of the barrel, there are inlet, or fill, ports *3* through which fuel enters the barrel and delivery passages *14* connecting the barrel bore with the inclined passages drilled in hydraulic head *2*. Through this passages fuel is delivered to delivery-valve holders *1* and thence to the appropriate fuel injectors by high-pressure injection lines. The barrel is held to the hydraulic head by a cap nut, a locating pin being used between these components to make the inclined passages of the barrel and head coincide. The barrel is sealed on the outside by rubber rings.

The distributor-type pumps of the more recent designs have their barrels made integral with the head.

The lower part of the barrel has a reduced outside diameter and carries geared sleeve *7* that imparts rotation to the plunger.

A recess made in the central part of the barrel accommodates metering (control) sleeve *13* used to change the amount of fuel delivered by the pumping element.



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Pumping element (section) of a distributor-type fuel-injection pump

1 – delivery-valve holder;
2 – hydraulic head;
3 – inlet (fill) port;
4 – barrel;
5 – plunger;
6 – idler gear;
7 – geared sleeve;
8 – plunger spring;
9 – cam;
10 – tappet;
11 – tappet locating bolt;
12 – control shaft arm;
13 – metering (control) sleeve;
14 – delivery passage;
15 – check valve;
16 – delivery valve;
17 – delivery-valve stop

The plunger has one center-drilling and two cross-drillings at the top and an annular groove for the lower spring seat and flats fitting in the drive guide in sleeve *7* at the bottom. The plunger is moved up by roller tappet *10* and down by spring *8*.

The tappet reciprocates in a bore in the pump housing. Mounted in the lower part of the tappet shell is a roller which is free to rotate on its pin. The tappet receives its motion from a cam carried on the camshaft of the pump.

The camshaft is supported by ball bearings mounted in the lower part of the pump housing. In two- and four-cylinder engines, the injection pump camshaft carries only one cam, while in six-cylinder engines, there are two cams on the camshaft. Each cam has as many lobes as there are cylinders that are supplied with fuel by the pumping element operated by the cam. For example, in a six-cylinder engine, each cam *9* has three lobes. In such a pump, the plunger makes three double strokes and a complete turn about its axis in one complete revolution of the camshaft. In a four-cylinder engine, the injection pump cam has four lobes.

The plunger is rotated by the geared sleeve which is driven from the governor shaft through idler gear *6*.

The hydraulic head of each section of the delivery-type fuel-injection pumps for six-cylinder engines is fitted with three delivery-valve holders *1*, while that of the pumps for four-cylinder engines has four such holders. Each delivery-valve holder houses check valve *15* and delivery valve *16*, both valves being spring-loaded against their seats.

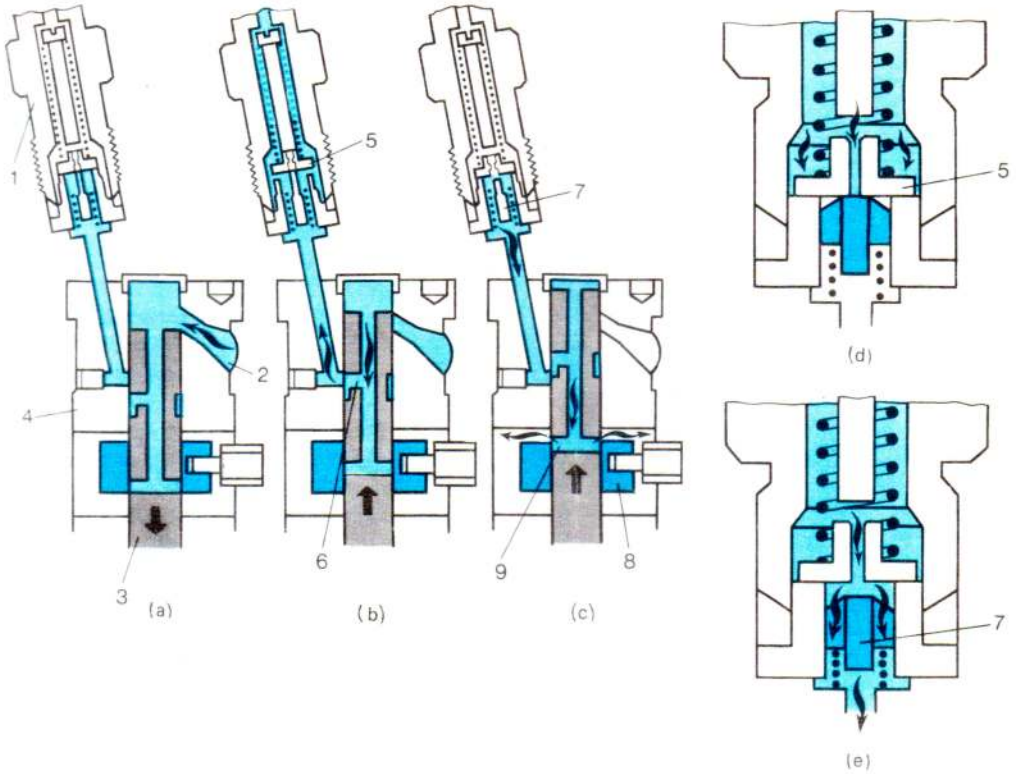
As plunger *3* moves down (Fig. 60*a*), it uncovers inlet (fill) port *2* of the barrel, and fuel under the transfer-pump pressure fills the barrel space vacated by the plunger. As the plunger moves up, some of the fuel filling the barrel is expelled through the open inlet port. As soon as the upper edge of the plunger covers the inlet port, the fuel pressure in the barrel builds up rapidly, and when the upper cross-drilling (distribution passage *6*) in the rotating plunger registers with one of the delivery passages of the barrel, the fuel is delivered through the associated delivery-valve holder *1* and high-pressure injection line to the appropriate fuel injector (Fig. 60*b*). During injection, delivery valve *5* and check valve *7* lift 0.5 to 0.6 mm and let the fuel pass to the injector.

Fuel delivery continues until the upper edge of the lower cross-drilling (spill, or cut-off, passage *9*) in the plunger passes the upper edge of the metering (control) sleeve *8* (Fig. 60*c*). When the spill passage opens, fuel at high pressure spills back through the center-drilling and the spill passage in the plunger to the reservoir area of the pump, and valves *5* and *7* lower (Fig. 60*d*). The delivery valve snaps onto its seat, but some of the fuel contained in the high-pressure injection line flows back by inertia through an orifice in the delivery valve, depressing the check valve off its seat in the delivery valve. As a result, the fuel pressure in the injection line is suddenly reduced, causing the fuel injector to stop injecting (delivering) fuel as suddenly.

The ending of fuel delivery, hence the amount of fuel delivered, is varied by changing the position of the metering sleeve on the plunger in relation to the spill passage. The higher the position of the metering sleeve on the plunger, the later the ending of delivery occurs and the greater the amount of fuel delivered by the pump. When the metering sleeve is moved all the way down, the spill passage in the plunger remains uncovered, so that no fuel can be trapped above the plunger. This is the no-fuel position.

When the engine is running, the beginning of fuel delivery is governed by an automatic injection advance device mounted in the rear part of the distributor-type fuel-injection pump.

The automatic injection advance device sets the injection advance angle at its optimum for a given engine speed. As the engine speed grows higher, the injection advance angle is automatically increased.



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Illustrating the operation of a pumping element of a distributor-type fuel-injection pump

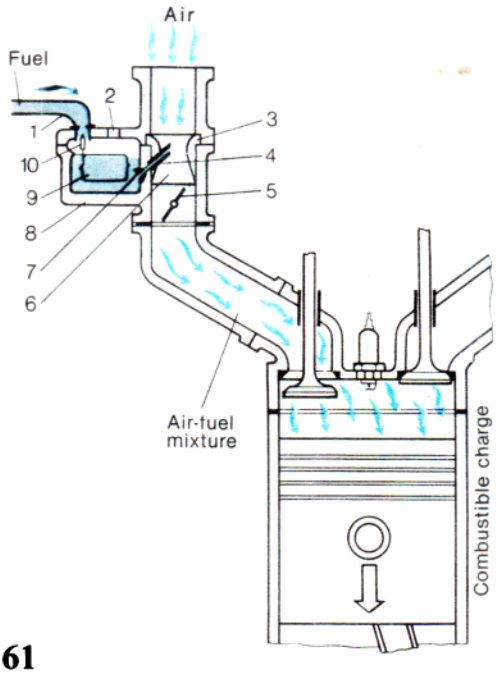
(a) fuel intake;
(b) fuel delivery;
(c) ending of fuel delivery;
(d) fuel cut-off;
(e) relief of high-pressure injection line;
1 – delivery-valve holder;
2 – inlet (fill) port;
3 – plunger;
4 – barrel;
5 – delivery valve;
6 – distribution passage;
7 – check valve;
8 – metering (control) sleeve;
9 – spill (cut-off) passage

8.8. Carburettors

The process of preparing an air-fuel mixture remote from the cylinders of an engine is called carburetion, and the device in which this process takes place is referred to as carburettor. The carburettor operates on the same principle as an ordinary atomizer in which a liquid flows out of a nozzle (a tube) under the effect of depression produced by air flowing around the nozzle and is broken by the air into very fine particles.

A SIMPLE CARBURETTOR (Fig. 61) consists of float chamber *8*, venturi *3*, fuel nozzle *4*, mixing chamber *6*, and throttle valve *5*. Fuel is delivered to the float chamber through fuel pipe *1* either by gravity or by a pump. The float chamber communicates with the mixing chamber via fuel nozzle *4* equipped with fuel (metering) jet *7*. The fuel jet is a plug with a metering orifice which lets pass through a definite amount of fuel per unit time.

Float *9* and needle valve *10* maintain a constant fuel level in the float chamber. As the float chamber is filled with fuel, the float ascends by virtue of its buoyancy and, actuating the needle valve through a lever, causes the valve to close. When the desired level is reached, the valve closes firmly on to its seat in the fuel inlet, so that no additional



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Illustrating the operation of a simple carburettor

1 – fuel pipe;
2 – float chamber air vent;
3 – venturi;
4 – fuel nozzle;
5 – throttle valve;
6 – mixing chamber;
7 – fuel jet;
8 – float chamber;
9 – float;
10 – needle valve

fuel can enter. When the fuel level drops, the float descends to open the needle valve, allowing more fuel to enter the float chamber. In actual operation, to meet a continuous demand for fuel, the float keeps the needle valve open by an amount just sufficient to make the fuel in the float chamber and fuel nozzle stay at a practically constant level 2 to 3 mm below the tip of the fuel nozzle.

During the intake stroke, a depression is created in the engine cylinder, which is transmitted to the mixing chamber of the carburettor. The air entering the carburettor passes through the narrow section of the venturi, as a result of which the air flow velocity is locally increased and the air pressure is correspondingly reduced. A pressure differential is thus produced between the float chamber and the venturi, which forces fuel to flow out of the fuel nozzle. The fuel delivered by the nozzle into the air stream is finely atomized, mixed with air, and partially vaporized to form an air-fuel mixture which is admitted to the engine cylinder.

THE AIR-FUEL MIXTURE is a mixture of air and vapours of finely atomized fuel (gasoline) that is prepared in the carburettor.

It takes 15 kg of air to burn completely 1 kg of gasoline. An air-fuel mixture in these proportions is called *normal*. If there is an excess of air, the mixture is referred to as *weakened* (15 to 17 kg of air per 1 kg of gasoline) or *lean* (more than 17 kg of air per 1 kg of gasoline). A mixture with an air-fuel ratio of 21:1 or higher will not ignite.

If there is an excess of fuel, the mixture is termed *enriched* (13 to 15 kg of air per 1 kg of gasoline) or *rich* (less than 13 kg of air per 1 kg of gasoline). With the air-fuel ratio lower than 5:1, the mixture will not ignite.

In actual service, the engine has to operate in conditions of constantly varying loads and speeds, and so, the compostion of the air-fuel mixture prepared by the carburettor must be changed to suit the engine requirements. For example, when starting from cold, the engine demands a very rich mixture, because under low-temperature conditions there will be less inflammable vapour per unit weight of gasoline, so that an excess of gasoline must be provided to obtain a readily combustible charge. For idling at normal operating temperature the engine still demands a fairly rich mixture, owing to the comparatively small amount of incoming fresh charge becoming diluted by unscavenged and inert exhaust gases. Under part-throttle running conditions. the engine mixture requirements become less demanding, for power output can be sacrificed to some extent in the interests of fuel economy. Therefore, the engine is satisfied by relatively lean mixtures. The excess of air in this case contributes to optimum fuel economy by ensuring complete combustion of the low proportion of gasoline

in the charge, which thus releases its maximum internal energy. However, a limit is imposed on the extent to which the mixture may be weakened, because ultimately incomplete combustion would cause misfiring. Finally, for full-throttle performance, the engine demands a rich mixture in order to produce its maximum power. The excess of gasoline is necessary in this case to ensure that the maximum possible amount of air, in the incoming charge, is utilized for the combustion process. Furthermore, the degree of mixture enrichment provided is generally greater than that demanded by the engine, so as to promote cooler running. As a result, both exhaust valve and spark plug operating temperatures are reduced, which extends their useful life under these running conditions.

It is necessary to distinguish between float carburettors and diaphragm carburettors. The starting engines used for starting modern tractor diesel engines are equipped with diaphragm carburettors.

DIAPHRAGM CARBURETTOR. The main component parts of the diaphragm carburettor are as follows (Fig. 62): diaphragm *9* sandwiched between carburettor body *3* and cover *8*, fuel-nozzle-and-main-jet* assembly *6*, throttle valve *2*, and choke valve *7*.

The diaphragm serves to control the amount of fuel entering the carburettor, so that a constant fuel level is maintained in the fuel nozzle.

The space above the diaphragm serves as a fuel reservoir. The space below the diaphragm is vented to the atmosphere through a hole. Fuel from the fuel tank enters the fuel reservoir of the carburettor (the space above the diaphragm) through valve *12*, a screen filter, and inlet fitting *4*. The amount of fuel entering the fuel reservoir is controlled by valve *12* which is carried on the right-hand end of a rocking lever and is pressed against its seat by spring *11*. The left-hand end of the rocking lever rests against the center of the diaphragm.

To enrich the air-fuel mixture during starting, the diaphragm can be forced to deflect by pushing on diaphragm depressor button *10* which is located in the lower part of the carburettor. Pushing on the button will cause the diaphragm to deflect upward and open valve *12*. Fuel will then fill the space above the diaphragm and flow into the mixing chamber of the carburettor through the fuel-nozzle-and-main-jet assembly.

The main metering system of the carburettor comprises fuel-nozzle-and-main-jet assembly *6* and the mixing chamber which occupies the center portion of the carburettor. When the engine is running under load, both the choke and throttle valves are open. As the piston moves up, atmospheric air passes with a high velocity through the mixing chamber of the carburettor and enters the crankcase of the engine *(*remember that this is a two-stroke engine*)*. A high depression is produced above the fuel nozzle, causing fuel to spout out of the nozzle. The fuel is atomized in the air stream, and the air-fuel mixture thus formed flows into the engine crankcase. As the fuel is consumed, the pressure in the fuel reservoir drops, causing the diaphragm to deflect upwards. The rocking lever end resting against the center of the diaphragm is thus lifted, making the other end of the rocking lever lower and move valve *12* away from the valve seat to allow more fuel to flow into the carburettor. After the space above the diaphragm has been filled with fuel, the pressure on both sides of the diaphragm becomes equalized, the diaphragm returns to its initial position, and the valve closes the fuel inlet to the carburettor.

When the engine is idling (Fig. 62*b*), choke valve *7* is open, whereas throttle valve *2* is almost fully closed. The flow of incoming air attains its maximum speed, hence the minimum pressure, at the edges of the throttle valve. Therefore, fuel does not discharge from the fuel nozzle, but flows instead through idle fuel jet *14* and the idle passage to the discharge port, called the idle port, from which it emerges into the main air stream just behind the throttle

* A jet is a component having an orifice to meter liquid flow.

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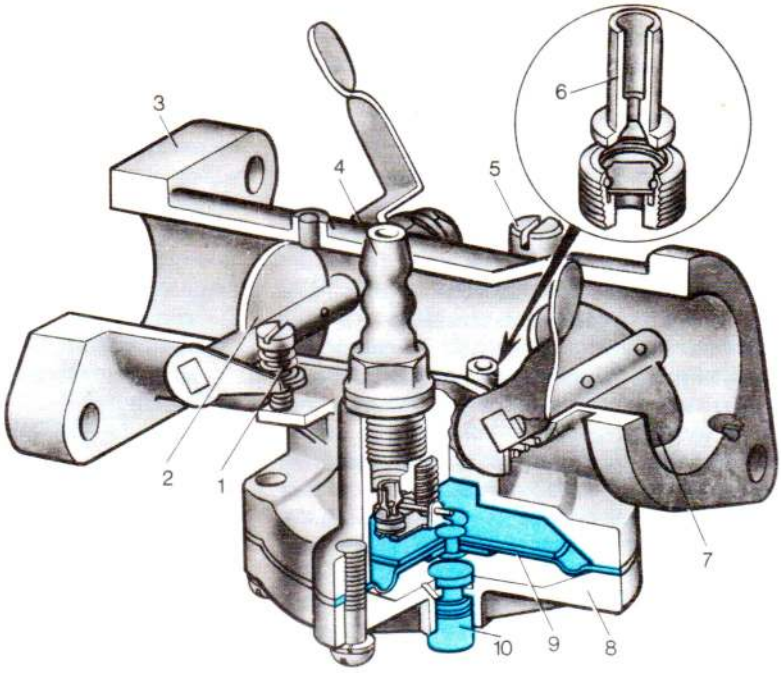
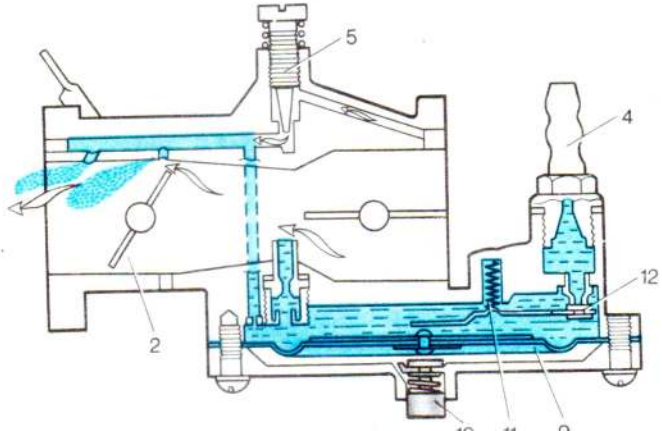
Diaphragm carburettor

(a) construction;
(b) illustrating the operation of the carburettor;
1 – throttle (idle) stop screw;
2 – throttle valve;
3 – carburettor body;
4 – fuel inlet fitting;
5 – idle mixture adjusting screw;
6 – fuel-nozzle-and-main-jet assembly;
7 – choke valve;
8 – cover;
9 – diaphragm;
10 – diaphragm depressor button;
11 – spring;
12 – valve



(a)



(b)

valve edge. Some air comes through air-bleed passage *13* and blends in the form of tiny bubbles with the fuel flowing through idle fuel jet *14*.

The size of the air-bleed hole can be varied by means of adjusting screw *5* to adjust the idle mixture strength. Turning the screw in makes the mixture richer. If the screw is turned out, the mixture is made leaner. The minimum amount of air-fuel mixture delivered by the carburettor during idling is set by throttle, or idle, stop screw *1* which limits the maximum amount by which the throttle valve can be closed.

To supply the very rich mixture required when the engine is started from cold, the choke

valve is closed. As a result, a high depression is produced in the mixing chamber, which causes large quantities of fuel to discharge from both the main fuel nozzle and idle port.

A by-pass flap valve is used in front of the fuel-nozzle-and-main-jet assembly to avoid overchoking when starting the engine with the choke valve closed.

The throttle valve serves to control the amount of air-fuel mixture admitted to the engine and hence the power it develops. The choke valve serves to control the amount of air entering the carburettor, hence the strength of the air-fuel mixture. If less air is admitted to the mixing chamber (i.e., if the choke valve is gradually closed), the mixture is enriched.

There being no air filter, the carburettor air horn is closed with a cover when the engine is stopped, so as to prevent the ingress of dust into the carburettor. An insulating gasket is interposed between the carburettor body and the engine cylinder to minimize heat transfer to the fuel supply.

AUTOMOBILE-TYPE FLOAT CARBURETTOR. The engine of an automobile has to operate in conditions of frequently varying speeds and loads, and so it is equipped with a more complex carburettor than the one considered above. Modern automobile engines use double-barrel down-draft carburettors.

The carburettor (Fig. 63) consists of the following three structural components that are bolted together: float chamber body *12*, cover *6*, and mixing chamber body *16* which is made integral with the housing of pneumatic-centrifugal maximum-speed governor *17*. Sealing gaskets of gasket board are interposed between the float chamber cover and body and between the float chamber body and the mixing chamber body.

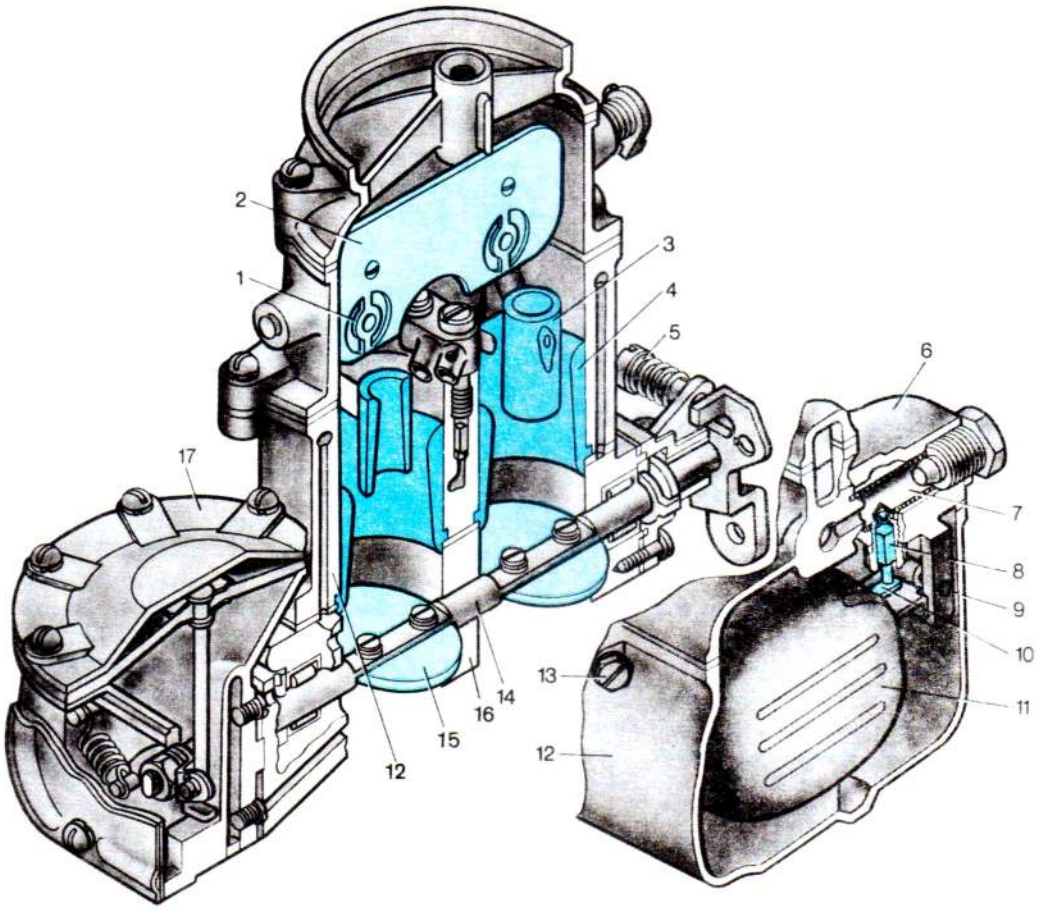
The float chamber body accommodates two large (primary) venturis *4* and two small (auxiliary) venturis *3*, emulsion tubes (open to the small venturis), air-bleed and fuel jets. All the jet passages are provided with plugs *13* through which access can be gained to the jets without disassembling the carburettor. The float chamber houses float *11* pivotted on pin *9* and needle valve *8* that closes the fuel inlet. The float and the valve maintain a constant fuel level in the float chamber and fuel discharge nozzle. The fuel level in the float chamber and the condition of the float mechanism can be checked through a sight glass provided in the side wall of the float chamber.

Mounted in the float chamber cover is choke valve *2* provided with two by-pass flat valves *1*.

The mixing chamber body houses two throttle valves *15* mounted on a common spindle. To supply the engine with the air-fuel mixture of correct proportions under various operating conditions, modern automobile carburettors are provided with the following metering systems: main metering system, idle system, cold starting system, economizer system, and accelerating-pump system.

Let us consider the operation of the carburettor under various engine running conditions. Both barrels of the carburettor operate in parallel, but independently, each barrel delivering air-fuel mixture to its own bank of cylinders. Each barrel has its own main metering system and idle system. The choke valve, float chamber, and economizer and accelerating pump systems are common to both carburettor barrels.

THE MAIN METERING SYSTEM (Fig. 64*a*) of each carburettor barrel includes large (primary) *7* and small (auxiliary) venturi *5*, discharge tube *1*, main fuel jet *4*, and main air-bleed jet *2*. Emulsion-discharge tube *1* is provided with perforations situated just above its central part, through which the air passing through main air-bleed jet *2* is added to the main metering system fuel. During engine operation, fuel flows from float chamber *3* into the small venturi through the main fuel jet and discharge tube. The amount of fuel leaving discharge tube *1* (with the throttle valve half open) is greater than that entering the tube via main fuel jet *4*. The fuel level in the discharge tube falls and the amount of air admitted to the discharge tube via main air-bleed jet *2* is increased accordingly. The cross-sectional areas of the main fuel and air-bleed jets are selected so as to make the composition of the air-fuel mixture suitable for economical part-throttle running.



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K-126Б Model automobile carburettor

1 – valve;
2 – choke valve;
3 – small (auxiliary) venturi;
4 – large (primary) venturi;
5 – throttle stop screw;
6 – float chamber cover;
7 – screen filter;
8 – needle valve;
9 – float pivot pin;
10 – float lever arm;
11 – float;
12 – float chamber body;
13 – plug;
14 – throttle spindle;
15 – throttle valve;
16 – mixing chamber body;
17 – maximum-speed governor

THE IDLE SYSTEM (Fig. 64*b*) enables the engine to run free at a low crankshaft rotational frequency. The system includes idle fuel jet *8*, air-bleed jet *12*, idle well and passage *11*, and idle mixture adjusting screw *9*. For the sake of simplicity, only one venturi is shown in Fig. 64*b, c*, and *d*. With throttle valve *6* nearly closed, a high depression is produced below the valve, which is transmitted to float chamber *3* via lower port *10* (called the idle port), which is situated below the throttle edge, and idle passage and well *11*. This depression is high

enough to cause fuel to flow from the float chamber to the idle port through main fuel jet *4*. idle fuel jet *8*, and idle well and passage *11*. While passing through the idle passage, the fuel is mixed with air admitted through air-bleed jet *12* and upper port *10* (referred to as the transfer port), which is located just above the throttle edge. The emulsion formed in the idle passage discharges through the idle port and is atomized by the incoming air stream.

The engine idling conditions are adjusted by varying the relative amounts of air and fuel mixture delivered into the incoming air stream and also the amount of air admitted to the idle system. The former adjustment is provided by idle mixture adjusting screw *9*, which is screwed into the mixing chamber body at the junction of the idle passage with idle port, and the latter, by a slow-running air regulating screw similar to screw *5* of Fig. 62.

THE ECONOMIZER SYSTEM, also known as the power system (Fig. 64*c*), enriches the mixture for maximum power under full-throttle running conditions, i. e., under conditions of high speed of heavy load when the intake manifold depression is low. The system includes submerged fuel valve *15* loaded by spring *16*, which by-passes the main fuel jet and communicates with the discharge nozzle, economizer jet *17*, and operating linkage components. When the throttle valve is opened more than three-fourths its fullest extent, lever *18* carried on the throttle spindle pulls on connection *14* which moves operating stem *13* down. The stem depresses fuel valve *15* off its seat, and extra fuel flows from the float chamber to discharge tube *1* of the main metering system via the open valve and economizer jet *17*.

THE ACCELERATING-PUMP SYSTEM (64*d*) serves to enrich momentarily the air-fuel mixture fed to the engine by injecting a controlled and metered quantity of additional fuel into the incoming air stream when the throttle valve is opened suddenly. The system consists of cylindrical well *20* communicating with the float chamber via an opening closed by fuel inlet check valve *22*, plunger *23*, fuel outlet check valve *19*, and jet *24*.

When the throttle valve is suddenly opened, lever *18* rapidly pulls on connection *14* to depress plunger *23*. This action causes the fuel filling the pumping chamber to close inlet check valve *22* and, opening outlet check valve *19*, discharge into the mixing chamber via jet *24*.

The starting system serves to supply the very rich mixture required when the engine is started from cold. This purpose is generally accomplished by providing a choke batterfly valve which is similar to the throttle valve, but situated between the carburettor air intake and the venturi. The choke valve is mechanically interconnected with the throttle valve, so that when it is fully closed, the throttle valve is slightly opened to admit the enriched mixture to the cylinders. In operation, the choke valve is completely closed during the initial cranking of the engine, so that a high depression is created in the carburettor, causing fuel to discharge from the main fuel nozzle idle ports.

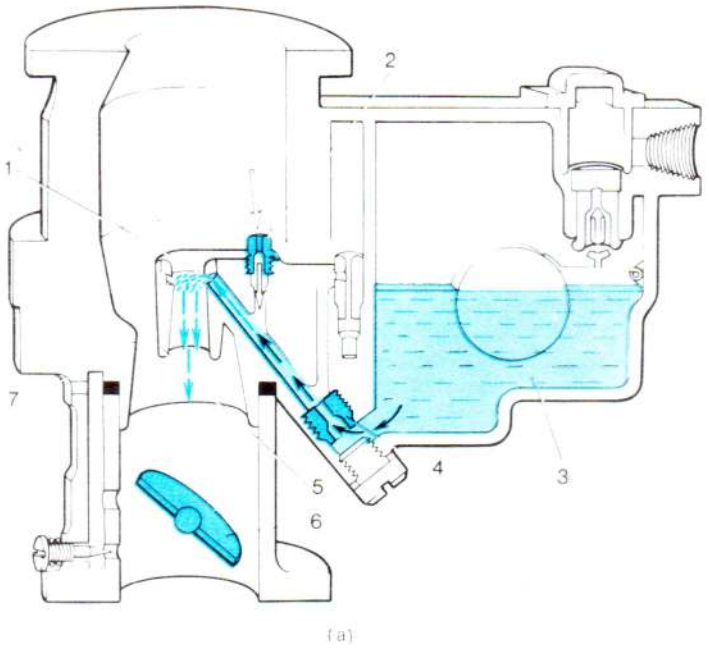
The choke valve is equipped with two spring-loaded by-pass flat valves which open automatically once the engine fires consistently. As the engine warms up to its normal operating temperature, the choke valve is gradually opened to its fullest extent. The choke valve remains fully open under all engine running conditions. It is operated manually by a flexible cable connected to a dashboard control button.

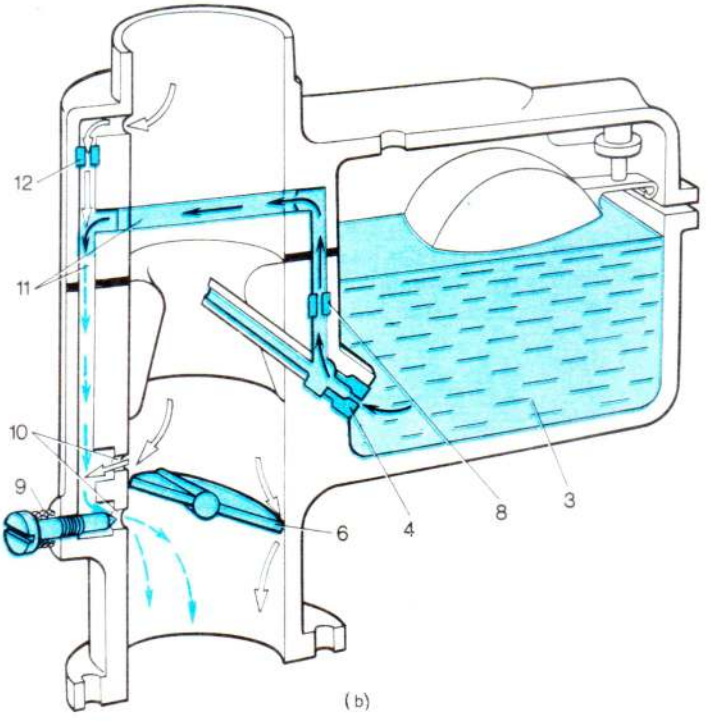
The throttle valve has a duel control: by a dashboard control button (which is used to set the engine speed at the desired fixed level, for example, when warming up the engine) and by a spring-loaded foot pedal, termed the accelerator pedal.

8.9. Engine Speed Governing

During operation, the load on the engine of an automobile or tractor frequently varies, depending on the ambient conditions (lay of the ground, soil condition, etc.). These load variations cause the engine speed to change accordingly, provided the position of the throttle valve or fuel control rack remains unchanged.

When the load on the engine is decreased, the engine speed may rise beyond safe limits,





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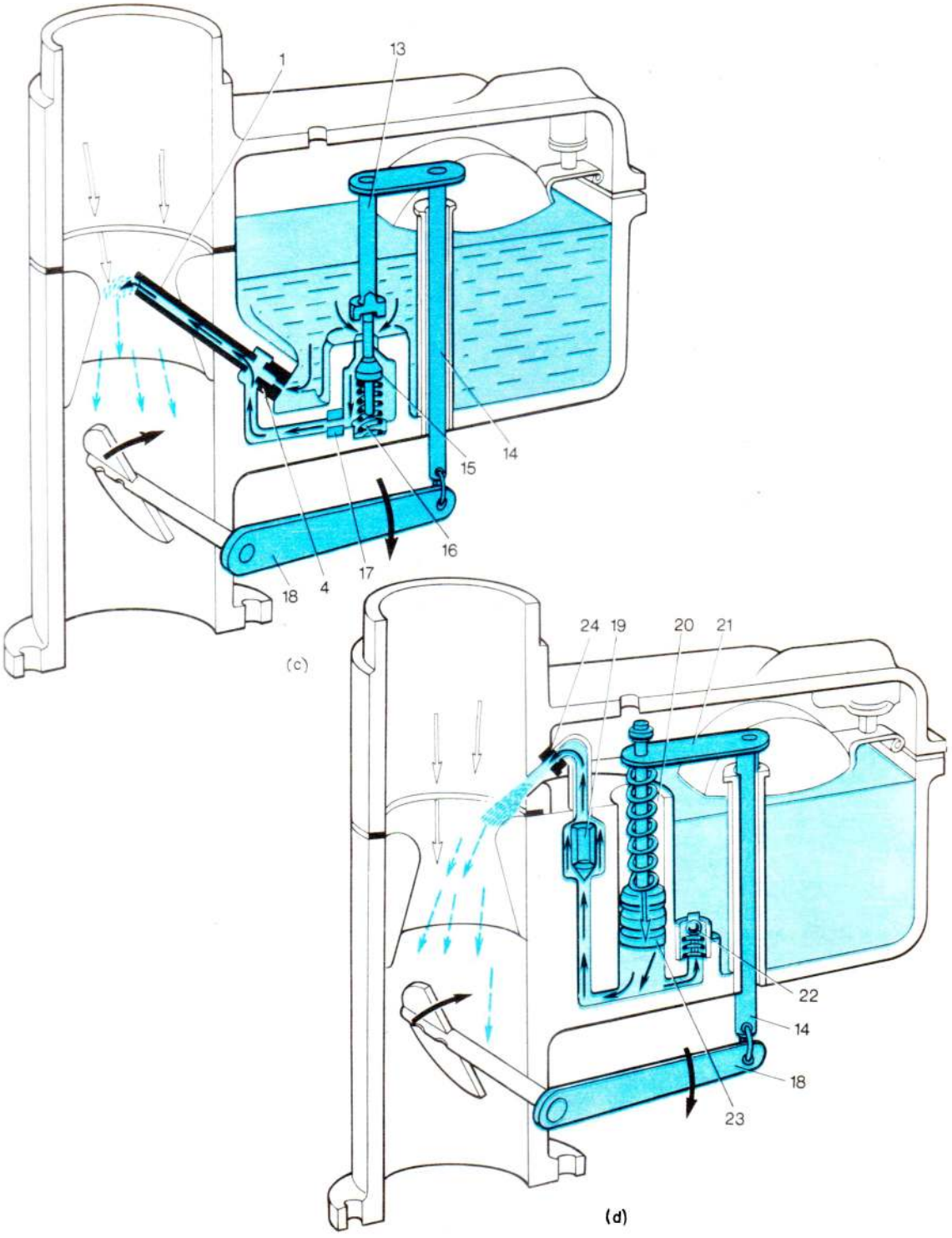
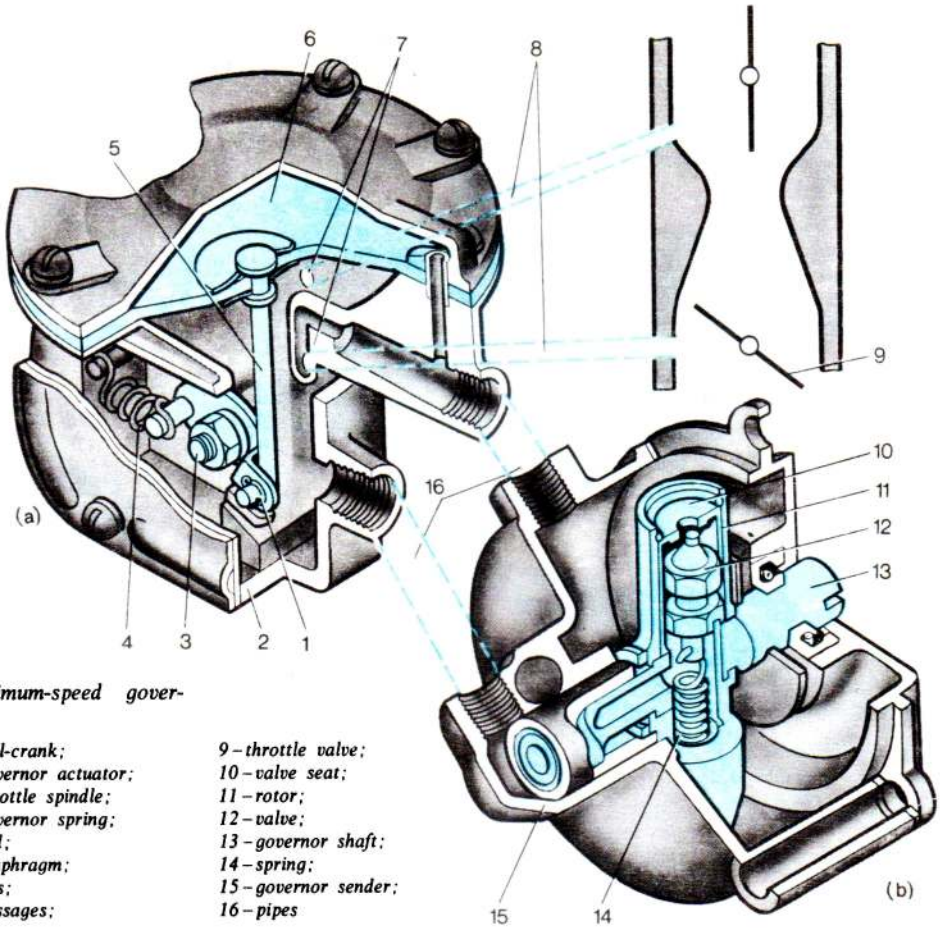
Fuel metering systems of a carburettor

(a) main metering system;
(b) idle system;
(c) economizer system;
(d) accelerating-pump system;
1 – discharge tube;
2 – main air-bleed jet;
3 – float chamber;
4 – main fuel jet;
5 – small (auxiliary) venturi;
6 – throttle valve;
7 – large (primary) venturi;
8 – idle fuel jet;
9 – idle mixture adjusting screw;
10 – transfer and idle ports;
11 – idle well and passage;
12 – air-bleed jet;
13 – operating stem;
14 – connection to throttle linkage;
15 – fuel valve;
16 – spring;
17 – economizer jet;
18 – throttle valve lever;
19 – fuel outlet check valve;
20 – cylindrical well;
21 – pump pusher strip;
22 – fuel inlet check valve;
23 – plunger;
24 – accelerating-pump jet


1
13
15
14
16
18
4
17
(c)
24
19
20
21
22
14
18
23
(d)



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Maximum-speed governor

1 – bell-crank;
2 – governor actuator;
3 – throttle spindle;
4 – governor spring;
5 – rod;
6 – diaphragm;
7 – jets;
8 – passages;
9 – throttle valve;
10 – valve seat;
11 – rotor;
12 – valve;
13 – governor shaft;
14 – spring;
15 – governor sender;
16 – pipes

causing accelerated wear of the engine working parts and increased fuel consumption. Moreover, to ensure high standard of work in performing many field operations requires that the land speed and the power takeoff speed of the tractor-operated implements used should remain constant, which means that the tractor engine speed should not vary. This can only be accomplished if the amount of air-fuel mixture or fuel delivered to the engine cylinders is varied in accordance with the changes in the engine load. A device for automatically controlling the speed of an engine by regulating the intake or injection of fuel, so that the engine speed is maintained at the desired level under all conditions of loading, is termed the governor.

Governor control may be effected by centrifugal (mechanical), hydraulic, pneumatic or combined (pneumatic-centrifugal) means. Speed governors may be classed as speed-limiting, constant-speed or all-speed. Speed-limiting and constant-speed governors are used on automobile engines and on auxiliary engines employed for starting tractor diesel engines. An automobile engine governor is in essence a maximum-speed governor. Modern tractor diesel engines use all-speed governors.

GOVERNOR (Fig. 65) is of pneumatic-centrifugal type. It comprises two mechanisms: centrifugal governor sender *15* and diaphragm-operated governor actuator *2*. The centrifugal governor sender includes rotor *11* whose shaft *13* receives rotation from the engine camshaft. The sender unit is mounted on the timing gear cover. The rotor houses valve *12* which is pulled away from its seat by spring *14*.

The governor actuator includes diaphragm *6* which is connected by rod *5* to one end of bell-crank *1*. The other end of the bell-crank is connected with governor spring *4*. The bell-crank is fixed to throttle spindle *3*. The throttle control mechanism incorporates a special claw coupling which enables the governor actuator to close and open the throttle valve irrespective of the position of the accelerator pedal. The spaces above and below the diaphragm are interconnected through the governor sender by pipes *16*. On the other hand, the space above the diaphragm communicates with the carburettor chamber below the throttle valve and that below the diaphragm, with the space below the choke valve, via passages *8*.

So long as the engine speed remains below the preset maximum (3200 rpm), the centrifugal force of valve *12* is insufficient to overcome the tension of spring *14*, and so the valve stays open. As a result, the spaces above and below the diaphragm communicate with each other through the governor sender. When the maximum speed is attained, the centrifugal force of valve *12* overcomes the resistance offered by spring *14*, and the valve closes on to its seat, thus breaking communication between the spaces above and below the actuator diaphragm. This action causes the depression communicated from the carburettor chamber to the space above the diaphragm, via lower passage *8*, to grow higher. If the engine speed increases further, this depression becomes sufficiently high for the diaphragm to deflect upward against the governor spring force and close the throttle valve by a certain amount, thus reducing the engine speed.

THE CONSTANT-SPEED GOVERNOR (Fig. 66) of a starting engine is a centrifugal ball type. It is intended to hold the engine at nominal speed, regardless of the load.

The main component parts of the governor are a housing, a shaft with a drive disc, a spring, and ball-shaped weights (balls).

Governor housing *6* is held to the engine crankcase through the medium of an adaptor plate. Governor shaft *9* rotates together with drive disc *10* whose slots accommodate balls *11* that are sandwiched between thrust washer *12* and conical-shaped movable disc *8*.

The movable disc is pressed against the balls by bell-crank *5* loaded by spring *3*. Rigidly fixed on pivot pin *7* of the bell-crank is external governor lever *2* which is connected with throttle rod *1*. When the engine is not operating, the spring forces the movable disc to the extreme left-hand position and rod *1*, to the extreme right-hand position. With the throttle rod in this position, the throttle valve is fully open. During engine operation, the centrifugal forces of the rotating balls cause the balls to move outward against the spring force and displace the movable disc to the right and the throttle rod to the left, thus closing the throttle valve.

With a steady load on the engine, an equilibrium exists between the centrifugal force of the rotating balls and the governor spring force. If the load on the engine is increased, the engine speed, hence the governor shaft speed, starts dropping. In this case, the centrifugal force of the balls decreases, and the governor spring, acting through the ball-crank, moves throttle rod *1* to the right to open the throttle valve. As a result, the engine speed rises until its nominal value is reached. As the engine load is reduced, the engine speed rises accordingly. The centrifugal force of the rotating balls then increases and, overcoming the governor spring force, moves throttle rod *1* to the left to close the throttle valve. This causes the engine speed to drop down to the nominal value.

The desired engine speed is set by varying the pre-load on the governor spring by means of adjusting screw *4*. This is done at the factory, after which the screw is locked in place by a lock nut and sealed. It is absolutely forbidden to adjust the engine speed under field

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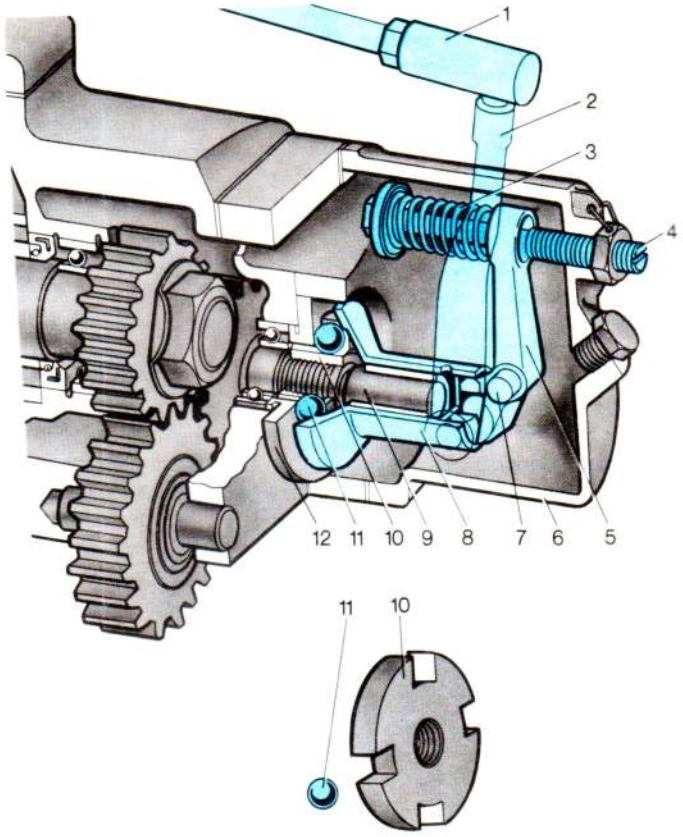
Constant-speed governor

1 – throttle rod;
2 – external lever;
3 – spring;
4 – adjusting screw;
5 – bell-crank;
6 – housing;
7 – pivot pin;
8 – movable disc;
9 – governor shaft;
10 – drive disc;
11 – ball;
12 – thrust washer



conditions. If it had been possible for the tractor operator to change the force of spring *3* by a special control lever, the governor action on the throttle valve would have started at any selected engine speed, i.e., the governor would have become an all-speed type.

8.10. All-Speed Governors

As its name implies, the all-speed governor has the ability to maintain any selected engine speed from idling to maximum.

The multi-element fuel-injection pump considered earlier in the text uses a small-size all-speed governor (Fig. 67).

GOVERNOR USED ON MULTI-ELEMENT FUEL-INJECTION PUMPS. The small-size all-speed governor has four flyweights *6* pivoted to flyweight carrier, or spider, *2* which is freely mounted on camshaft *1* of the fuel-injection pump. The connection between the camshaft and the flyweight carrier is provided by helical spring *3* which lessens the nonuniformity of flyweight rotation. Freely mounted on the camshaft shank is sliding sleeve *7* with a thrust ball bearing.

Mounted on a common pivot pin in the rear part of the governor are main lever *14* and intermediate lever *9*. The upper end of the intermediate lever is linked with fuel control rack *18* of the pump. The intermediate lever carries roller *8*, corrector *12*, and the fastening pin of booster spring *15*. The intermediate and main levers are connected together by bolt *16* that provides for the necessary angular free play

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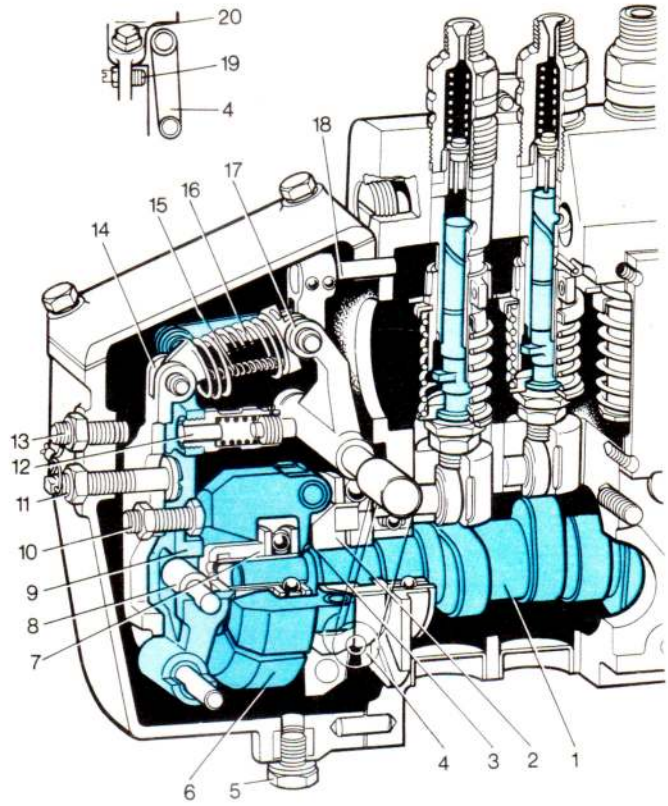
Small-size all-speed governor

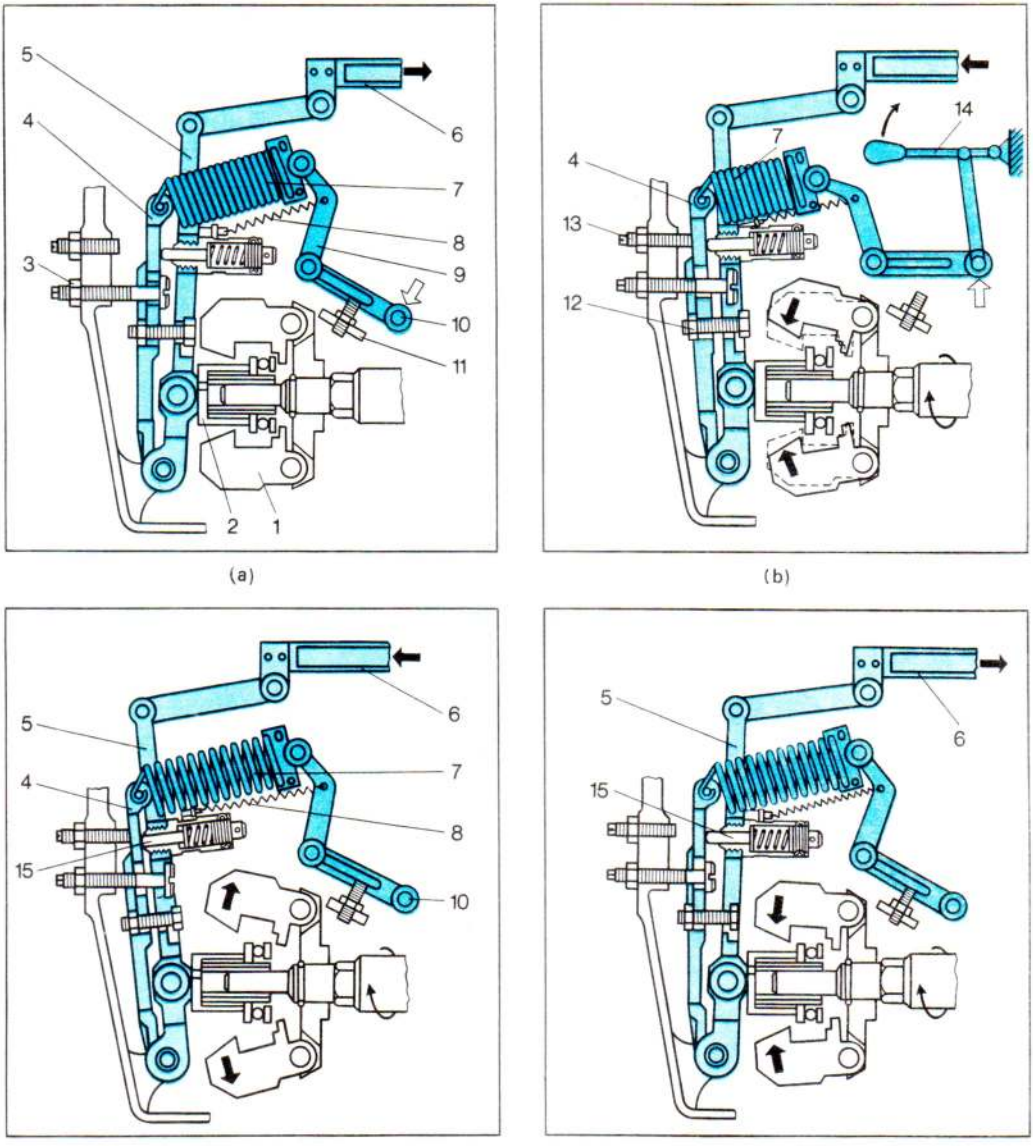
1 – camshaft;
2 – flyweight carrier (spider);
3 – helical spring;
4 – control lever;
5 – drain plug;
6 – flyweight;
7 – sliding sleeve;
8 – roller;
9 – intermediate lever;
10 – connecting bolt;
11 – nominal-speed adjusting screw;
12 – corrector;
13 – fuel shut-off adjusting screw;
14 – main lever;
15 – booster spring;
16 – governor spring;
17 – lever;
18 – fuel control rack;
19 – maximum-speed adjusting screw;
20 – inspection-hole plug



between them. The main lever is connected through the intermediary of governor spring *16* with lever *17* which is rigidly fixed on flats of the shaft of control lever *4*. Screwed in a boss on the side wall of the governor housing is maximum-speed adjusting screw *19* which limits the maximum tension of the governor spring. Screwed in the rear wall of the governor housing are nominal-speed adjusting screw *11* and fuel shut-off adjusting screw *13*. Provision is made in the governor for automatic boosting of the amount of fuel metered per cycle at the initial cranking speed. This is effected by booster spring *15* which connects the intermediate lever with lever *17*.

OPERATION. When starting the engine (Fig. 68*a*), control lever *10* is turned until it abuts against maximum-speed adjusting screw *11*, so that lever *9* connected to the control lever extends springs *7* and *8*. Governor spring *7* moves main lever *4* until it rests against the head of nominal-speed adjusting screw *3*, while booster spring *8* moves intermediate lever *5* together with fuel control rack *6* forward (to the right in Fig. 68*a*) to provide for the increased fuel delivery necessary for starting the engine. Once the engine has started, the centrifugal forces of flyweights *1* cause the weights to move outward. The flyweight fingers move sliding sleeve *2* backward, which in turn moves backward the intermediate lever and fuel control rack, thereby decreasing the fuel delivery.

If speed control lever *14* is moved all the way up (Fig. 68*b*), governor spring *7* will first contract completely and then, acting as a rigid rod, will move main lever *4* backward until it comes to rest against fuel shut-off adjusting screw *13*. At the same time, bolt *12* connecting the main and intermediate levers will cause the



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Illustrating the operation of the small-size all-speed governor of Fig. 67

(a) position of governor components when starting the engine;
(b) position of governor components when stopping the engine;
(c) position of governor components at high-idle speed;
(d) position of governor components with the engine overloaded;
1 – flyweight;
2 – sliding sleeve;
3 – nominal-speed adjusting screw;
4 – main lever;
5 – intermediate lever;
6 – fuel control rack;
7 – governor spring;
8 – booster spring;
9 – lever;
10 – control lever;
11 – maximum-speed adjusting screw;
12 – connecting bolt;
13 – fuel shut-off adjusting screw;
14 – speed control lever;
15 – corrector

intermediate lever to move the fuel control rack to the no-fuel position, and the engine will thus be stopped.

When the engine is operating at the maximum idle speed, generally referred to as the high-idle speed (Fig. 68*c*), control lever *10* is brought to rest against the maximum-speed adjusting screw. Having no load applied to it, the engine starts increasing its speed. The centrifugal force of the governor flyweights grows higher and moves levers *4* and *5* to the left against the force of springs *7* and *8*. At the same time, lever *5* moves the fuel control rack toward the low-fuel position. As a result, the engine speed decreases until the centrifugal force of the rotating flyweights is offset by the force of governor spring *7* and the fuel control rack comes to rest in a certain intermediate position. In this position of the governor, the rod of corrector *15* is completely depressed, and the main and intermediate levers are tightly pressed together, so that they act as a single whole.

When the engine is fully loaded, its speed drops, and the centrifugal force of the governor flyweights is reduced accordingly. The governor spring forces the main lever together with the intermediate lever forward until the main lever rests against the head of the nominal-speed adjusting screw. At the same time, the fuel control rack is moved toward the full-fuel position. If the load on the engine remains unchanged, the governor spring force and the flyweight centrifugal force come to equilibrium, and the governor maintains the nominal engine speed until either force is changed. If the engine load is changed, this equilibrium will be disturbed, and the intermediate lever will move the fuel control rack to change the fuel delivery accordingly.

If the engine is overloaded (Fig. 68*d*), the engine speed, hence the centrifugal force of the governor flyweights, becomes so low that the spring of corrector *15* is allowed to expand and, with its rod abutting against the main lever, moves intermediate lever *5* together with fuel control rack *6* forward to additionally increase the fuel delivery. This enables the engine to develop more torque and cope with the overload. The corrector can provide an increase of 15 to 20% in fuel delivery as compared to that at the rated engine load.

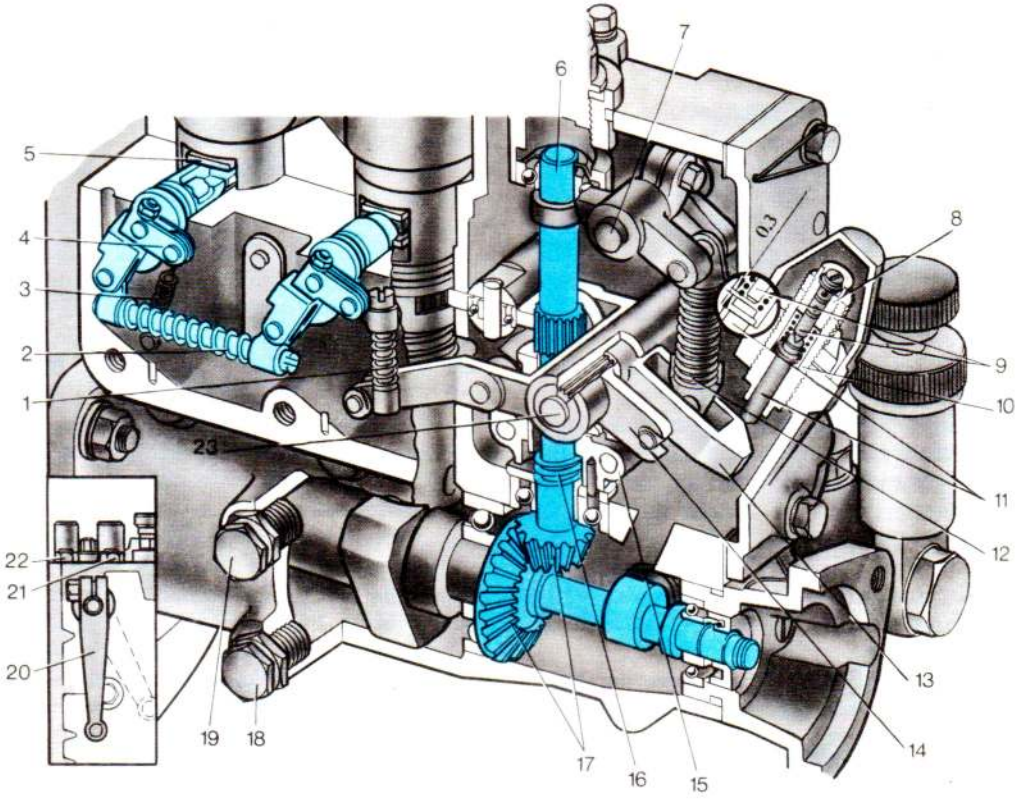
Above we have considered the operation of the governor with the control lever brought to rest against the maximum-speed adjusting screw. By moving speed-control lever *14* it is possible to change the degree of extension of governor spring *7*, hence the selected engine speed. When operating the tractor under conditions of low load, it is advisable to select a reduced engine speed in order to save fuel.

GOVERNOR USED ON DISTRIBUTOR-TYPE FUEL-INJECTION PUMPS (Fig. 69). Governor shaft *6* is driven from the pump camshaft through a pair of bevel gears *17* and is supported in a vertical position by two ball bearings. Carried on the lower part of the governor shaft is flyweight carrier (spider) *15* which is connected to the governor shaft through the medium of helical spring *16*. The spring serves to protect the governor mechanism from overloads that may be caused by sharp changes in the governor shaft speed. Pivoted to the carrier are flyweights whose fingers are fitted with rollers that act upon a sliding sleeve carried on the governor shaft. The sleeve is acted upon from the opposite side by bell-crank *14* loaded by spring *12*.

The tension of spring *12* can be changed by means of speed-control lever *20* carried on shaft *7*. The movement of speed-control lever *20* is confined between two stop screws, namely, maximum-speed adjusting screw *21* and fuel shut-off adjusting screw *22*. The bell-crank is connected by a linkage with metering *(control)* sleeve *5* of the pump.

The governor incorporates a corrector that helps the engine to handle short-term overloads by additionally increasing the delivery of the pump. Corrector holder *10* accommodates spring-loaded pin *11* whose stroke is limited by stop *9*. When the corrector is inoperative, the pin protrudes to its maximum from the corrector holder, so that there is a clearance of 0.3 mm between the inner end of the pin and the pin stop. The spring load on the corrector pin can be adjusted by means of screw *8*.

OPERATION (Fig. 70). When the engine is



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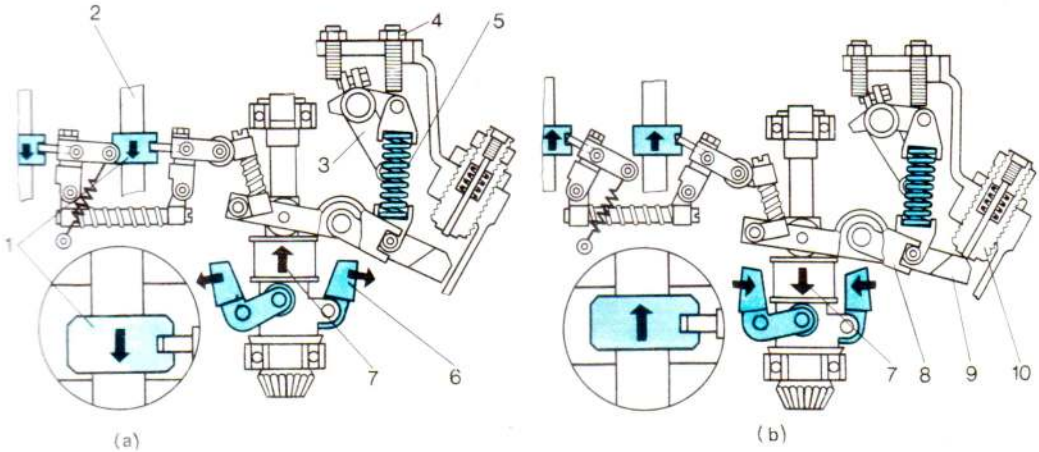
Governor of a distributor-type fuel-injection pump

1 – minor adjusting link;
2 – major adjusting link;
3 – spring;
4 – metering-sleeve control lever;
5 – metering (control) sleeve;
6 – governor shaft;
7 – control-lever shaft;
8 – corrector-spring adjusting screw;
9 – corrector pin stop;
10 – corrector holder;
11 – corrector pin;
12 – main spring;
13 – corrector lever;
14 – bell-crank;
15 – flyweight carrier (spider);
16 – helical spring;
17 – governor bevel gear drive;
18 – oil drain plug;
19 – oil filler plug;
20 – speed-control lever;
21 – maximum-speed adjusting screw;
22 – fuel shut-off adjusting screw;
23 – bell-crank pivot shaft

running, the governor shaft rotates together with the flyweights. Under steady-state conditions, the centrifugal force of the flyweights is counterbalanced by the force of main spring *5*, and so metering sleeve *1* is retained in a definite position and the engine crankshaft revolves with the selected speed defined by the position of speed-control lever *3*.

As the load on the engine is reduced, the engine speed grows higher. The rising centrifugal force of rotating flyweights *6* (Fig. 70*a*) overcomes the force of main spring *5* and moves sliding sleeve *7* upward. At the same time, the linkage moves pump metering sleeve *1* down, thereby decreasing the pump delivery. The engine speed drops until the main governor spring force and the flyweight centrifugal force come to equilibrium again, so that the engine crankshaft again revolves with the selected speed.

With the full load on the engine. speed-control lever *3* is brought to rest against maximum-speed adjusting screw *4*. An equilib-



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Illustrating the operation of the distributor-type fuel-injection pump governor of Fig. 69

a) position of governor components with decreasing load on the engine;
b) position of governor components with a short-term overload on the engine;
1 – metering sleeve;
2 – plunger;
3 – speed-control lever;
4 – maximum-speed adjusting screw;
5 – main spring;
6 – flyweight;
7 – sliding sleeve;
8 – bell-crank;
9 – corrector lever;
10 – corrector holder

rium exists between the main governor spring force and the flyweight centrifugal force, and the metering sleeve of the pump is maintained in such a position as provides for the pump delivery required under given conditions of load and speed.

In the case of a short-term overload (Fig. 70*b*), the engine speed drops temporarily. The centrifugal force of the rotating flyweights decreases, sliding sleeve *7* is forced down by the main spring, and bell-crank *8* and corrector lever *9* are turned counterclockwise. Lever *9* depresses the corrector pin into holder *10* against the force of the corrector spring. This action allows the other end of the bell-crank to move further down, so that the metering sleeve is moved through the linkage toward the increased-fuel position to enable the engine to overcome the overload. If the engine speed drops further, it is necessary to decrease the load on the engine to prevent it from stalling. After overcoming the overload, the engine speed increases, the increased centrifugal force of the governor flyweights overcomes the main governor spring force, and the sliding sleeve comes to rest in a position where lever *9* just touches the top of the corrector pin.

8.11. Fuel System Troubles

Experience gained in operating automotive engines has shown that most engine troubles rest with the fuel system. The more common fuel system troubles are fuel leaks through badly sealed fuel line connections, air leaks past air cleaners and filters, and clogged fuel lines and filters. Besides, carburettor engines may suffer from carburettor troubles resulting in inadequate air-fuel mixture composition (too lean or too rich); diesel engines may develop troubles due to air finding its way into the fuel lines, poor atomization of fuel by the fuel injectors, or wrong injection timing.

Such troubles may cause hard starting, lack of power, misfiring, smoky exhaust, or sudden stalling.

Fuel leaks can be detected by visual inspection. The leaks, if revealed, are eliminated by tightening up the leaky connections or by replacing defective gaskets.

If the engine does not start, the first thing to

do is to make sure that there is fuel in the tank and that the fuel shut-off cock is open. Then check the operation of the fuel (transfer) pump and make sure that the fuel lines and filters are not clogged. Use a tire pump to clear clogged fuel lines, if any. Next check the carburettor (if your engine uses one) for clogged jets. Use a tire pump to clear clogged carburettor jets, if found. Never use wire to do the job, for this may damage jet orifices.

A tractor starting engine may fail to start because of an incorrect proportion of lubricating oil in its fuel (remember that this is a two-stroke engine). So, check for this condition and, if necessary, prepare a fresh mixture. Never mix lubricating oil with fuel directly in the engine fuel tank, but use a separate container instead.

A diesel engine will not start if air gets into the fuel system, for in this case, the fuel-injection pump will compress air bubbles in its barrels instead of delivering fuel into the engine cylinders. Should this prove to be the case, bleed the fuel system, using the hand primer pump. Expel air first from the primary fuel filter, then from the secondary fuel filter, and finally from the fuel-injection pump head.

Wrong injection timing may also be the cause of hard starting. Therefore, check for this condition as well and make corrections, if necessary.

Should all the above corrective measures prove to be no help, check the fuel injectors for spray pattern and injection pressure, and replace any one found to be defective. Still better, replace the injectors outright, if spares are available.

If a diesel engine lacks power and, in addition, misses or has a smoky exhaust, one should first of all locate the cylinder that is most responsible for these troubles. To do this, disconnect each fuel injector in turn from the fuel-injection pump. This can be done by backing off 1.5 to 2 turns the injection-line union nuts on the pumping elements. The disconnection of any injector, except for the one in the misfiring cylinder, will affect the operation of the engine.

Loss of power that is not coincidental with an increased exhaust smoke density is most probably caused by clogged fuel filters or worn pump plunger-and-barrel or injector nozzle-and-needle-valve assemblies. Therefore, the first thing to do in this case is to check the primary and secondary fuel filters and wash their filter elements, if necessary.

A reduction in engine power not attended by a smoky exhaust may be caused by a faulty fuel injector, clogged air cleaner, or incorrect injection timing. So, check the air cleaner and, if necessary, wash the oil bath and screen filters with diesel fuel. Fill the bath with fresh oil. Check and adjust (if necessary) the injection timing.

Never disassemble the fuel injectors or fuel-injection pump under field conditions. Any operations involving the disassembly of these units can only be done by skilled mechanics at specialized shops.

In carburettor engines, loss of power, resulting from defects in the fuel system, is due to an air-fuel mixture that is either too lean or too rich.

The operation of an engine on too lean a mixture is attended by popping in the carburettor. This is because the rate of combustion of a lean mixture is so slow that it is still burning in the cylinder when the intake valve opens on the next intake stroke, so that the flame passes back around the open intake valve and through the intake manifold and carburettor.

A lean mixture condition may result from either too little fuel or too much air in the combustible charge. The amount of fuel in the charge may be reduced because of clogged fuel tank air vent, clogged fuel lines, filters or carburettor fuel jets, defective fuel pump or too low fuel level in the carburettor float chamber. An increased amount of air in the charge may be due to carburettor body and intake manifold air leaks.

The clogged fuel tank air vent should be cleared from dirt or ice (in winter time). Clogged fuel filters should be disassembled, cleaned and washed in clean gasoline. Damaged fuel pump diaphragms should be replaced. Poorly fitting fuel pump valves should

be cleaned and, if necessary, replaced. Air leaks should be eliminated by tightening the carburettor body and intake manifold fasteners or by replacing damaged sealing gaskets.

A rich mixture will also cause a loss of power. Excessive quantities of fuel will not vaporize and burn completely. Liquid fuel washes the lubricant from the cylinder walls, allowing the piston rings to make metal-to-metal contact. Scuffed rings and excessive oil and fuel consumption will result.

An excessively rich mixture may result from defects in the carburettor and also from too high a fuel pump pressure which forces the carburettor needle valve off its seat, causing flooding.

An engine may show a loss in power when unfiltered air enters the cylinders, causing increased wear in the piston rings and cylinder liners. Piston-ring wear results in poor compression, hard starting, and increased exhaust smoke density. Therefore, the engine should be systematically checked for air-intake leaks. To do this, remove the precleaner cap, run the engine at a moderate speed, and tightly close the stand-up pipe. If there are no air leaks past the air cleaner, the engine will stall. If the engine does not stall, tighten up all the fasteners of the air-intake components.

Unstable idling of a carburettor engine may result from clogged idle jets in the carburettor or from poor idle mixture adjustment.

A diesel engine will race (i.e., develop excessively high speed) if there is too much oil in the governor housing or in the oil bath of the air cleaner, or else if the fuel control rack or some governor components are frozen. In this case, the engine must be stopped and the condition causing the trouble must be remedied.

Review Questions

1. List the grades of fuel used in carburettor engines.
2. What is the fuel the diesel engines run on?
3. Show in Fig. 45 the route of fuel from the fuel tank to a fuel injector.
4. Explain the operating principle of the centrifugal air cleaner.
5. What is the purpose of the turbocharger?
6. What is the purpose of making a hole in the fuel tank filler cap?
7. What is the difference between the automobile and tractor primary fuel filters?
8. How can the two-section secondary fuel filter be flushed without disassembly?
9. How can air be removed from the secondary fuel filter?
10. What is the purpose of the fuel transfer pump?
11. How can fuel be pumped into the carburettor by hand?
12. How does the fuel injector operate?
13. Explain the operation of a pumping element of a multi-element fuel-injection pump.
14. What is the major difference between plain reciprocating and distributor-type fuel-injection pumps?
15. How can one differentiate between lean and rich mixtures?
16. What is the purpose of the economizer system?
17. Describe the construction and operation of the accelerating pump.
18. What is an all-speed governor?
19. How can a defective fuel injector be traced on a running engine?
20. List the basic fuel system troubles.

Chapter 9
The Starting System

9.1. Engine Starting Methods

Ease of starting is one of the major performance characteristics of internal combustion engines. To start such an engine, it is necessary to spin the engine crankshaft with sufficient speed for good mixing of air and fuel and adequate compression and ignition of the combustible charge. The minimum speed with which the crankshaft of an engine should be rotated to ensure reliable starting of the engine is referred to as the cranking speed. It depends on the engine type and starting conditions.

The starting speed is 40 to 50 rpm for carburettor engines and 150 to 250 rpm for

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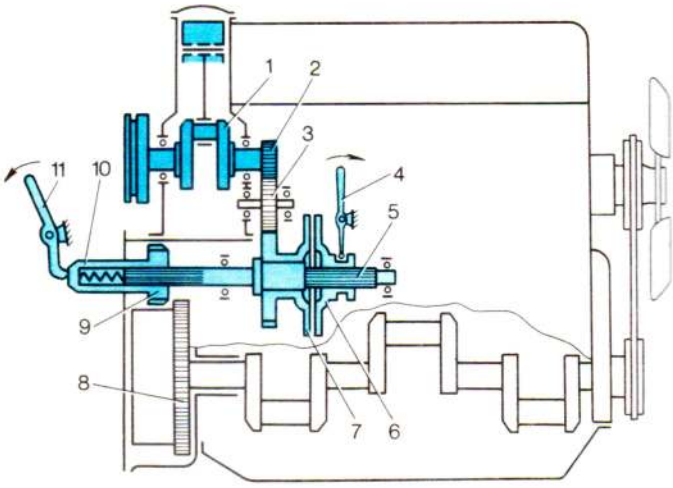
Schematic diagram of a starting device

1 – starting-engine crankshaft;
2 and 3 – gears;
4 – clutch lever;
5 – reduction-gear shaft;
6 and 7 – clutch driven and driving discs;
8 – flywheel ring (starter) gear of diesel engine;
9 – starter-gear;
10 – automatic starter-gear release mechanism;
11 – starter-gear control lever



diesel engines. Cranking the engine with a lower speed makes it more difficult for the engine to start, for in this case the charge has more time to escape through leaky joints and give off its heat of compression to the engine components, as a result of which both the pressure and temperature of the charge at the end of the compression stroke are reduced.

Much effort is required to crank the engine during starting, since it is necessary to overcome friction in the moving engine components and the resistance offered by the charge being compressed. This effort depends on the engine temperature, growing higher with decreasing temperature, because of the increasing viscosity of lubricating oil.

Internal combustion engines may be started by hand, by an electric starter motor or by an auxiliary engine.

Hand starting depends on the muscle power of the operator to turn the crank handle hooked to the engine crankshaft or to tug at the starting rope wound around the engine flywheel (in auxiliary engines used for starting diesel engines on tractors).

Electric starting is the most common method used for starting automobile engines and many tractor engines as well. The system is convenient to operate and considerably eases the driver's work, but requires skilled maintenance and has only a small store of energy, which limits the number of possible starting attempts. Many engines using an electric starting system are also provided with means for hand starting in case the storage battery or the starter motor should fail.

Starting with the aid of an auxiliary internal combustion engine is used with some diesel engines. This method is more dependable than the other two under any temperature conditions, but the starting procedure itself is more complex.

To facilitate the starting of diesel engines under low-temperature conditions, use is made of the compression release (decompressor) mechanism and heating devices.

Most automotive engines have their starting systems controlled remotely, from the driver's cab.

Where an auxiliary engine is used for starting a diesel engine the auxiliary engine cranks the main one through a reduction gear referred to as the starting-engine drive. The starting engine complete with its drive is usually called the starting device.

A schematic diagram of such a starting device is shown in Fig. 71 in blue ink. From crankshaft *1* of the starting engine rotation is

transmitted through gears *2* and *3* to clutch discs *6* and *7* and thence to reduction-gear shaft *5*. Starter-gear *9* carried on the splined end of the shaft can be thrown into engagement with flywheel ring (starter) gear *8* of the diesel engine by means of lever *11* to transmit rotation to the diesel crankshaft. After the diesel has started, starter-gear *9* is disengaged from the diesel flywheel ring gear by automatic release mechanism *10*.

9.2. The Starting Engine

The starting engine is a single-cylinder two-stroke carburettor type. The intake of the air-fuel mixture and the exhaust of the burnt gases are effected through ports in the cylinder walls that are opened and closed by the reciprocating piston.

CRANK MECHANISM. The base of the starting engine (Fig. 72) is formed by cast-iron crankcase *12* that is split in half vertically. The alignment of the crankshaft main bearings is ensured by two dowel pins. The crankcase is hermetically sealed, since it serves not only as an enclosure for the engine crankshaft, but also as a scavenging chamber. Plug *13* screwed in the lower part of the crankcase is used to drain condensate accumulated in the crankcase.

Mounted on top of the crankcase is cylinder *6* cast integral with gas passages and a water jacket. Cut in the cylinder walls are three pairs of ports – intake, scavenging (transfer), and exhaust. The intake ports located below both the scavenging and the exhaust ports communicate with a carburettor via a passage. The scavenging ports communicate with the crank chamber via two passages, and the exhaust ports communicate with exhaust pipe *1*. Attached to the cylinder are connections for exhaust gases and cooling water.

The cylinder is closed from the top by cylinder head *5*. The cylinder head is cast integral with a water jacket that communicates with the cylinder jacket. A metal-asbestos gasket is employed to seal the cylinder head to cylinder joint. Mounted on the cylinder head are scavenging and priming cock *4*, cooling water outlet connection *2*, and spark plug *3*.

The piston cast in an aluminium alloy has two grooves for compression rings. To prevent the free ends of the piston rings from interfering with the cylinder port windows, each ring is restrained from rotating by a tightly fitting steel peg let into its groove. To ensure correct installation of the piston relative to the cylinder ports during assembly, the piston head is marked with an arrow that points to the exhaust ports. The piston is connected to its connecting rod *15* by a hollow piston pin whose cavity is partitioned to prevent the transfer of gases from the exhaust ports to the intake ones. Pressed in the connecting rod small end is a plain bronze bushing, and two rows of cylindrical rollers are accommodated in the big end of the rod. The manner in which the connecting rod is assembled at the factory to the crankshaft is such that these parts cannot be disassembled under conditions of in-service repair.

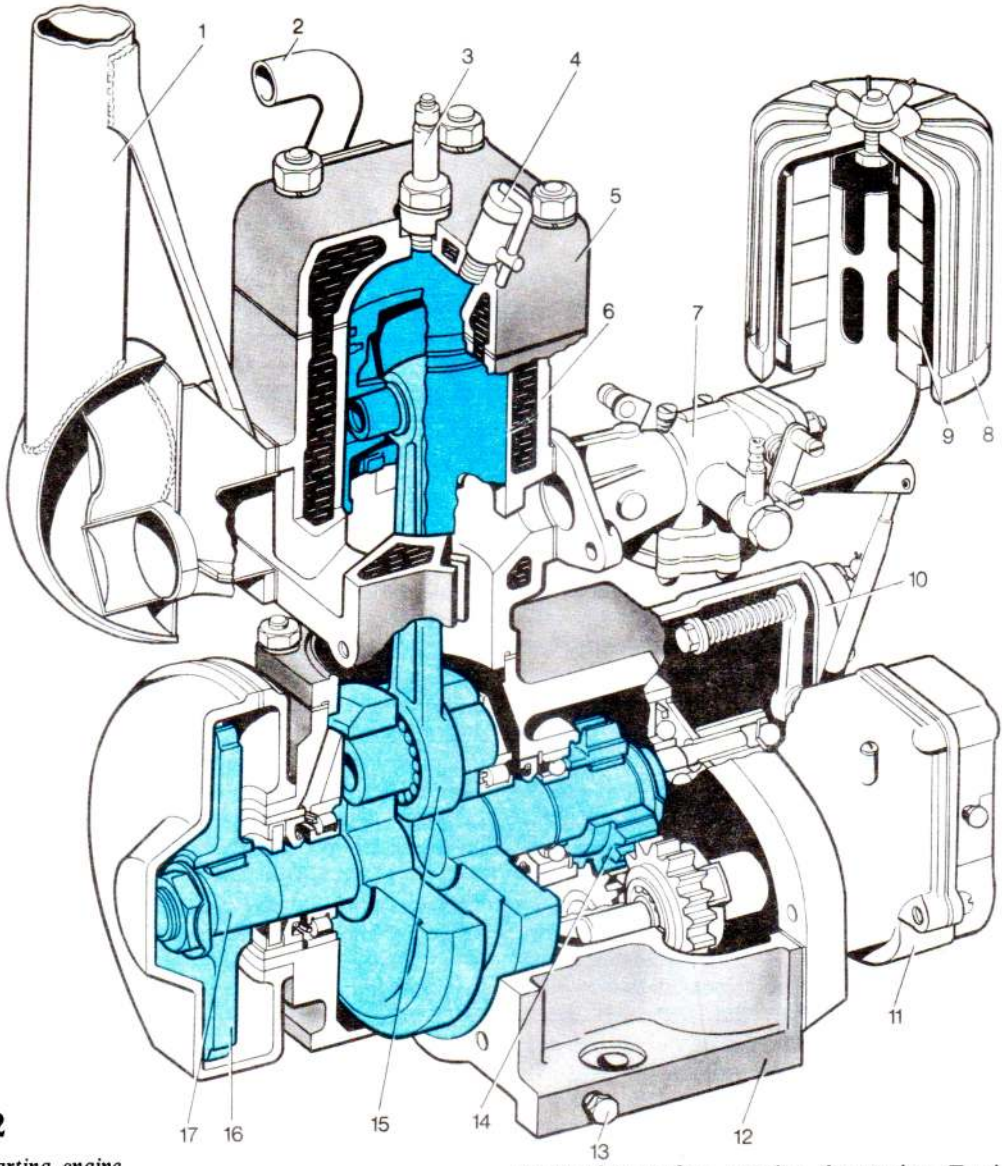
Crankshaft *17* is of built-up construction. Its crankwebs are made integral with the counterweights and are press-fitted on the front and rear half-shafts that serve as the main bearing journals. The crankpin is hollow and is pressed in the crankwebs. The crankshaft main bearing journals rotate in roller bearings mounted in the engine crankcase. Where its ends emerge from the crankchamber, the crankshaft is sealed by radial lip-type seals that prevent the leakage of the air-fuel mixture when it is being compressed in the crankcase.

Cranshaft gear *14* is keyed to the front end of the crankshaft and engine flywheel *16* carrying a ring gear is mounted on the rear end of the shaft.

Mounted on the front wall of the starting engine are carburettor *7* with an air cleaner, governor *10*, and magneto *11*.

Some starting engines are equipped with a back-up starting mechanism which is used in case the starter motor should fail. Both the back-up starting mechanism and the starter motor are mounted on the rear wall of the starting engine.

Gear *5* (Fig. 73) of the back-up hand starter is normally disengaged from idler gear *2*, and is thrown into mesh with this gear by the hand-



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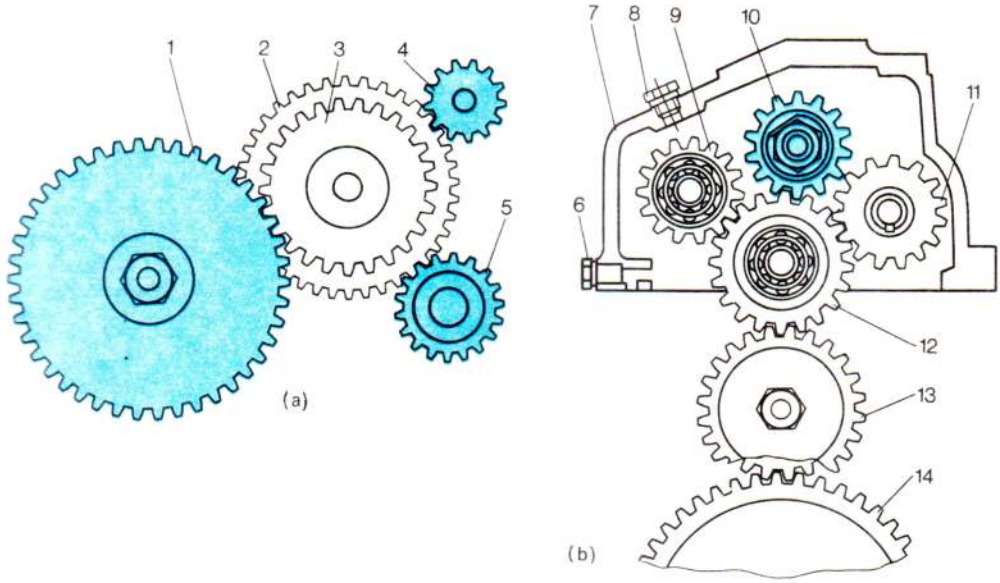
Starting engine

1 – exhaust pipe;
2 – cooling water outlet connection;
3 – spark plug;
4 – scavenging and priming cock;
5 – cylinder head;
6 – cylinder;
7 – carburettor;
8 – air cleaner cap (plastic);
9 – filter element (expanded polyurethane);
10 – governor;
11 – magneto;
12 – crankcase;
13 – condensate drain plug;
14 – crankshaft gear;
15 – connecting rod;
16 – flywheel;
17 – crankshaft

starter lever when starting the engine. During starting, one should first smoothly pull on the lever until gear *5* meshes with gear *2* and then sharply tug at it to impart rotation to the crankshaft of the starting engine through the idler gear and the flywheel ring gear. The mechanism of the back-up hand starter provides for the operator's safety in case the engine should kick back.



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Gear trains of a starting engine

a) starting gear train of the П-350 Model starting engine;
b) driving gear train of starting-engine drive;
1 – flywheel;
2 and 3 – idler gear;
4 – starter-motor gear;
5 – back-up hand-starter gear;
6 – condensate drain plug;
7 – crankcase;
8 – oil filler plug;
9 – magneto drive gear;
10 – crankshaft gear;
11 – governor drive gear;
12 – idler gear;
13 – driving cluster gear of starting-engine drive;
14 – clutch gear of starting-engine drive

Driven from crankshaft gear *10* through idler gear *12* are magneto drive gear *9*, governor drive gear *11*, and driving cluster gear *13* of the starting-engine drive. During assembly, gears *9*, *10*, and *12* are meshed according to timing marks stamped on them.

COOLING SYSTEM. The starting engine shares a common cooling system with the main engine. When the starting engine is idling, it is cooled by natural circulation of the cooling water through the cylinder jacket (thermo-siphon cooling) which is inadequate to the task, and so the engine overheats rapidly. Therefore, the starting engine must not be allowed to run idle for more than 2 minutes. When the starting engine is put under load, it spins the main engine crankshaft, hence the water pump which forces the water to circulate through the entire cooling system. The hot water flows from the cylinder head of the starting engine to that of the main engine, where it gives off its heat, thus warming up the main engine, while the cold water passes from the cylinder block of the main engine to the cylinder jacket of the starting engine to cool it. The starting engine can run under full load without overheating for no more than 15 minutes.

LUBRICATION SYSTEM. Lubrication of the two-stroke engines is complicated by the fact that the lubricating oil can neither be stored in the scavenging chamber, i.e., the crankcase, nor can it be reused after application because of contamination by the fuel charge. As it is therefore no longer practicable to use a forced circulation system, in which the oil is continuously recirculated, a total loss system is employed where fresh oil is continuously consumed. In practice, the lubricating oil is introduced into the fuel supply to form what is generally termed a petrol (gasoline-oil) mixture, so that in the process of carburation the working parts of the engine are lubricated in

aerosol fashion by oil mist. The starting-engine drive gears are lubricated with diesel oil which is poured in the drive housing through the hole closed by filler plug *8* in the upper part of the engine crankcase.

FUEL SYSTEM. The starting-engine fuel system includes a fuel tank with a fuel filter and a sediment trap, a carburettor with an air filter, and a governor. The system is described in detail in Chapter 8.

IGNITION SYSTEM. The system includes a magneto and a spark plug. It is described in detail in Chapter 19.

9.3. The Starting-Engine Drive

Starting-engine drives may be of a single- or a double-stage reduction-gear type. Described below is the single-stage reduction-gear type of starting-engine drive that is most commonly used on tractor diesel engines. The starting-engine drives that are used on the tractors studied in this book are all of similar construction. Some minor differences in the shape of their housings and construction of their control levers are due to the differences in design between the particular engines and tractors.

The starting-engine drive (Fig. 74) is enclosed in a housing atop which the starting engine is mounted. The starting-engine drive housing is bolted to the bell housing of the diesel engine. Shaft *12* of the drive is supported by two ball bearings. The front end of the shaft carries a clutch and the rear end, an automatic starter-gear release mechanism.

CLUTCH. The clutch is an overcenter multiple-disc wet type and serves to smoothly couple the crankshaft of the starting engine to that of the main engine. Clutch gear *10*, which is driven from the starting engine crankshaft, is freely supported on starting-engine drive shaft *12* by a plain bronze bushing that is pressed in the gear. Riveted to the gear is sheet-steel clutch driving drum *9* having four axial slots.

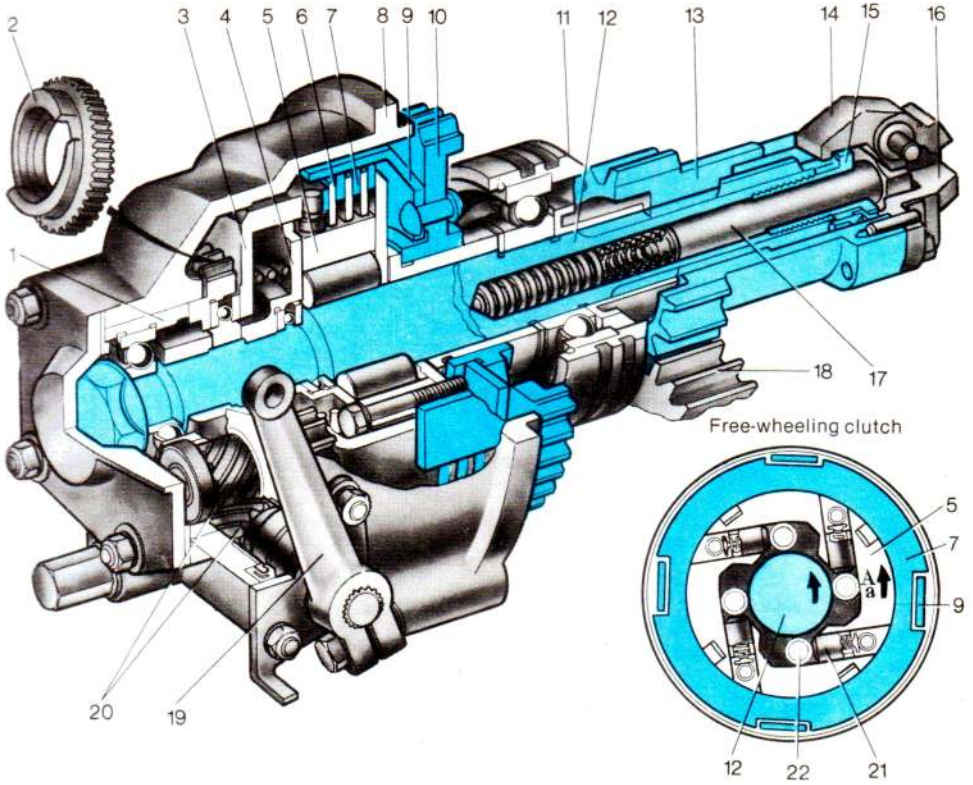
The clutch driving and driven discs are made of steel and have no friction linings. Driving discs *7* are provided with projections that fit in the slots of the driving drum, so that the discs rotate together with the drum. Similarly, driven discs *6*, which alternate with the driving ones, fit with their projections in the slots in driven drum *5* and rotate together with it. When the discs are pressed together, rotation is transmitted from the starting engine crankshaft to the starting-engine drive shaft via a free-wheeling clutch located inside the driven drum of the starting-engine drive clutch.

THE FREE-WHEELING CLUTCH includes rollers *22* which support the driven drum on the shaft. The rollers are accommodated in shaped recesses machined in the drum. Spring-loaded plungers *21* force the rollers into the narrow part of the recesses. The rollers are prevented from falling out of the recesses by a thrust disc and the flange of hub *4* bolted to the end face of the driven drum.

The free-wheeling clutch protects the starting engine from damage due to overrunning after the main engine starts by disconnecting the starting-engine drive shaft from the crankshaft of the starting engine. During starting, rotation is transmitted from the starting engine crankshaft to the driven drum of the starting-engine drive clutch. As the drum rotates, it causes the rollers to roll over stationary shaft *12* of the drive. As a result of friction between these components, the rollers are forced into the narrow part of the recesses in the drum where they jam and thus lock the drum to the shaft. In this position, the drum and the shaft rotate as a single whole.

When the main engine starts, its flywheel spins the starting-engine drive shaft much faster than it originally was spinning. The angular velocity *B* at the point *b* is higher than the angular velocity *A* at the point *a*, and therefore the starting-engine drive shaft will cause the rollers to move back out of the jamming part of the recesses in the driven drum of the starting-engine drive clutch, freeing the shaft from the starting engine. The free-wheeling clutch operates in its unlocked position not very long, since as the speed of the starting-engine drive shaft increases further, the automatic starter-gear release mechanism takes over and shifts starter-gear *13* out of mesh with ring gear *18*.

THE CLUTCH OPERATING MECHANISM consists of pressure plate *3*, sliding (pressure)



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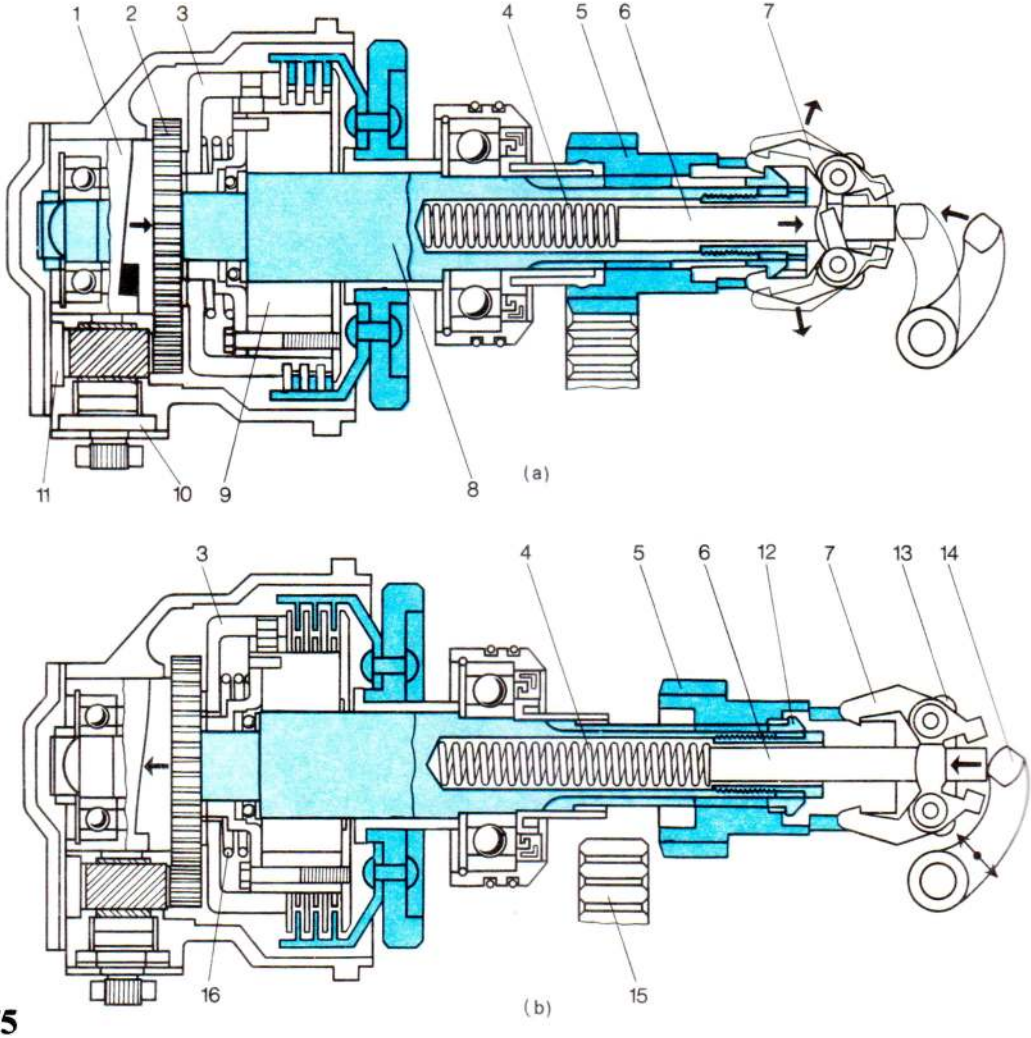
Starting-engine drive

1 – fixed thrust ring;
2 – sliding thrust ring;
3 – pressure plate;
4 – hub;
5 – driven drum;
6 – driven disc;
7 – driving disc;
8 – housing;
9 – driving drum;
10 – clutch gear;
11 – bearing housing with rubber sealing rings;
12 – shaft;
13 – starter-gear;
14 – flyweight;
15 – push-rod sleeve;
16 – carrier;
17 – push-rod;
18 – flywheel ring gear;
19 – lever;
20 – helical transmission gears;
21 – plunger;
22 – roller

thrust ring *2*, fixed thrust ring *1*, lever *19*, and three transmission gears – two helical gears *20* and one spur gear. The pressure plate is freely mounted on hub *4* and is connected to the clutch driven drum by pins fitting in the slots in the drum, so that the plate can move axially relative to the drum. The pressure plate is spring-loaded against the sliding thrust ring, a thrust ball bearing being used between them. The sliding thrust ring is made integral with a straight-cut gear that meshes with the spur transmission gear and is provided with two helical projections that are butted up against matching projections of the fixed thrust ring pressed in the starting-engine drive housing.

The clutch is operated by means of a control lever located in the driver's cab. A control rod is used to link the control lever with lever *19*. To engage the clutch, the control lever is moved down. This motion is transformed by the control rod, lever *19*, and transmission gears into a turning motion of sliding thrust ring *2* (Fig. 75*a*). As the sliding thrust ring turns, the helical projections on fixed thrust ring *1* force it to move to the right along starting-engine drive shaft *8*. This causes the pressure plate to press together the clutch driving and driven discs. Now rotation is transmitted from the clutch



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Illustrating the operation of the starting-engine drive

(a) engaged position;
(b) disengaged position;
1 – fixed thrust ring;
2 – sliding thrust ring;
3 – pressure plate;
4 – springs;
5 – starter-gear;
6 – push-rod;
7 – flyweight;
8 – starting-engine drive shaft;
9 – free-wheeling (overrunning) clutch;
10 – helical-gear shaft;
11 – helical-and-spur-gear shaft;
12 – special washer;
13 – flyweight carrier;
14 – lever;
15 – flywheel ring gear;
16 – clutch release spring

gear, which is driven from the starting engine crankshaft, to the clutch driven drum and thence to shaft *8* through rollers of free-wheeling clutch *9*.

To disengage the clutch, the control lever is moved up. This causes the sliding thrust ring to turn back to its initial position. Now clutch release spring *16* (Fig. 75*b*) forces pressure plate *3* to the left, releasing the clutch discs, so that no rotation is transmitted from the starting engine crankshaft to the starting-engine drive shaft.

AUTOMATIC STARTER-GEAR RELEASE MECHANISM. The mechanism serves to shift starter-gear *5* out of mesh with flywheel ring gear *15* of the diesel engine after it starts. It consists of flyweight carrier *13* coupled to the starter-gear, flyweights *7* provided with dogs, push-rod *6* loaded by two springs *4* (one inside the other), and lever *14* coupled to a control handle. The starter-gear is shifted into mesh with the flywheel ring gear by lever *14* and is retained in this position by the flyweight dogs that catch on to projections on special washer *12*. The springs force the push-rod to push against the flyweight fingers, thus forcing the flyweights toward each other.

After the diesel engine has started, its flywheel spins the starting-engine drive shaft, so that free-wheeling clutch *9* (Fig. 75*a*) disconnects the shaft from the starting engine. As the speed of the diesel engine grows higher, the centrifugal force of the rotating flyweights forces the weights outward. The flyweights disengage from the washer, and springs *4* force push-rod *6* to shift the starter-gear out of mesh with the flywheel ring gear of the diesel engine. In this way, the starting-engine drive is disconnected from the diesel engine.

9.4. Starting Device Troubles

To start a starting engine in good repair usually requires not more than three or four starting attempts. If the engine does not start, check the fuel and ignition systems (see Sections 8.1 and 19.3).

The starting engine will be hard to start if its compression is low. In this case, it is necessary to replace the piston rings because even if the engine does start, it will not develop its full power.

If the starting engine is noisy or knocks, the causes of engine troubles can be pinpointed by listening attentively to the engine operating under different conditions. A sharp, metallic, double-knock, generally audible with the engine idling, is the result of excessive piston pin clearance due to worn piston pin or connecting rod small end bushing. A rattle audible over the entire height of the cylinder is caused by excessively worn piston, or broken or worn piston rings, while dull knocks in the lower part of the engine, which become louder as the engine speed is increased, result from worn connecting rod bearing. A noisy engine must be repaired.

The starting engine may overheat if there is not enough water in the cooling system, or if the engine is operated under full load for more than 15 minutes at a time. Therefore, do not fail to check the water level in the cooling system and top it up, if necessary, and never use the engine for too long a time.

If the crankshaft of the diesel engine does not spin with the starting engine running at full speed, the trouble is with the starting-engine drive. The starting-engine drive clutch will slip if the clutch discs are excessively worn. In this case, it is necessary to adjust the position of the clutch lever.

If the starter-gear fails to remain in mesh with the flywheel ring gear, it is necessary to check the automatic starter-gear release mechanism and remedy the cause of trouble. This is most likely worn dogs of the flyweights or worn edges of the special washer. If the starter-gear is hard to shift into mesh with the flywheel ring gear, it is necessary to remove dents from the gear teeth.

Review Questions

1. Why is the diesel engine more difficult to start than the carburettor engine?
2. What are the methods for starting automotive engines? What are their advantages and disadvantages?
3. What are the differences between the starting and the main engines?
4. What are the main component parts of the starting-engine drive?
5. Describe the purpose and construction of the starting-engine drive clutch.
6. What is the purpose of the free-wheeling clutch? How does it operate?
7. Explain the purpose and operating principle of the automatic starter-gear release mechanism.
8. List the starting engine troubles.
9. What is the reason for the slipping of the starting-engine drive clutch?
10. List the automatic starter-gear release mechanism troubles.

Part III
CHASSIS

The chassis of the tractor and the automobile includes the drive line, running gear, and steering mechanism.

The drive line consists of units that transmit torque from the engine to the driving wheels and change this torque and the rotational frequency of the wheels both in magnitude and direction. The main drive-line units are shown schematically in Fig. 76.

Chapter 10
The Clutch

10.1. Single-Disc Clutch

The clutch allows the driver to couple the engine to or uncouple the engine from the transmission while he is shifting gears or starting the tractor or automobile moving from rest.

Modern tractors and automobiles use friction clutches, i.e., ones employing friction forces to transmit power. The friction surfaces in such clutches are provided by discs, whose number depends on the magnitude of torque to be transmitted. Most commonly used are single- and double-disc clutches.

Figure 77 shows a schematic diagram of a single-disc clutch. Clutch driving disc (pressure plate) *1* is connected to the engine flywheel, while driven disc *3* is mounted on transmission clutch (input) shaft *8*. The driven disc has splines in its hub that match splines on the input shaft. The disc is tightly clamped between the pressure plate and the flywheel by a series of coil springs, called the pressure springs, held between the clutch cover and the pressure plate. Owing to the friction forces arising between the friction surfaces of the flywheel, driven disc, and pressure plate, torque can now be transmitted from the engine to the transmission input shaft. In this position, the clutch is engaged.

The clutch is operated by the clutch linkage which carries the movement of clutch pedal *7* to clutch release (throw-out) bearing *6*. When the driver steps on the pedal, the clutch linkage, which includes an operating rod and a release fork, forces the release bearing inward (to the left in Fig. 77). As the release bearing moves left, it pushes against the inner ends of three release levers *5*. When the inner ends of the release levers are pushed in by the release bearing, the outer ends of the levers move the pressure plate to the right, compressing pressure springs *2*. With the spring pressure off the driven disc, spaces appear between the disc, the flywheel, and the pressure plate. Now the clutch is disengaged (released), and the flywheel can rotate without sending power through the driven disc. When the clutch pedal is released, the pressure springs force the pressure plate to the left. The driven disc is again clamped tightly between the flywheel and the pressure plate. The driven disc must again rotate with the flywheel. In this position, the clutch is engaged. The initial slipping of the driven disc, which occurs until the disc is fully clamped between the flywheel and the pressure plate, tends to make the engagement smooth. The clutch described above is known as the spring-loaded dry friction type.

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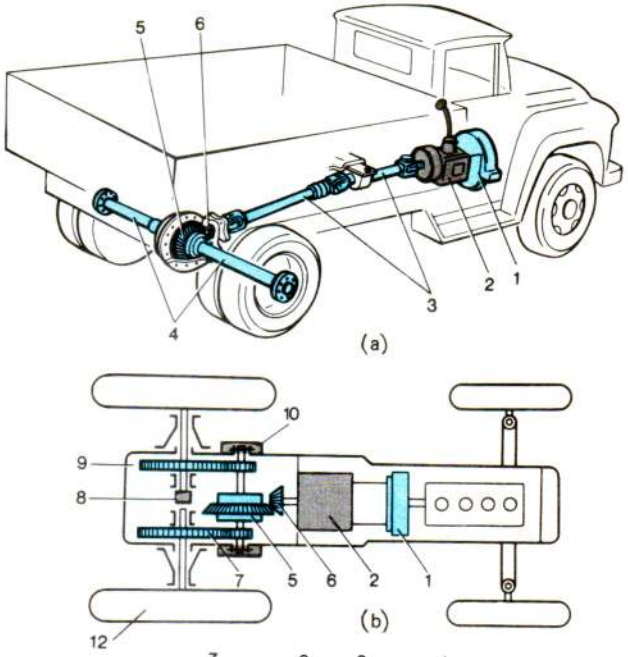
Schematic diagrams of drive-line arrangements

a) of an automobile;
b) of a wheeled tractor;
c) of a crawler tractor;
1 – clutch;
2 – transmission (gearbox);
3 – cardan drive (propeller shaft);
4 – half axles;
5 – differential;
6 – main drive;
7 – final drive;
8 – differential lock;
9 – rear axle;
10 – brake;
11 – steering mechanism;
12 – driving wheel (sprocket);
13 – intermediate drive shaft)



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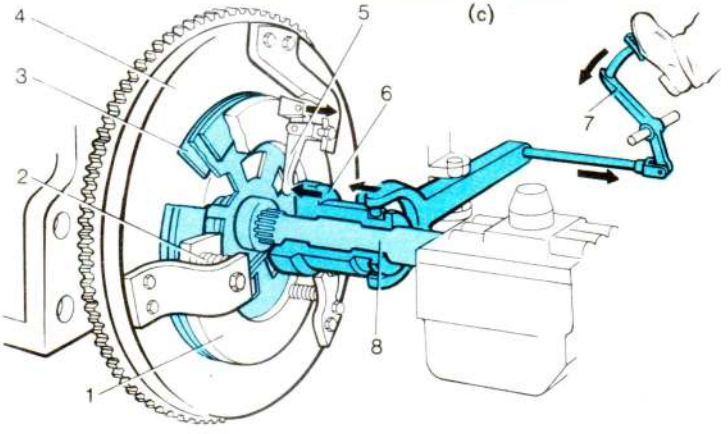
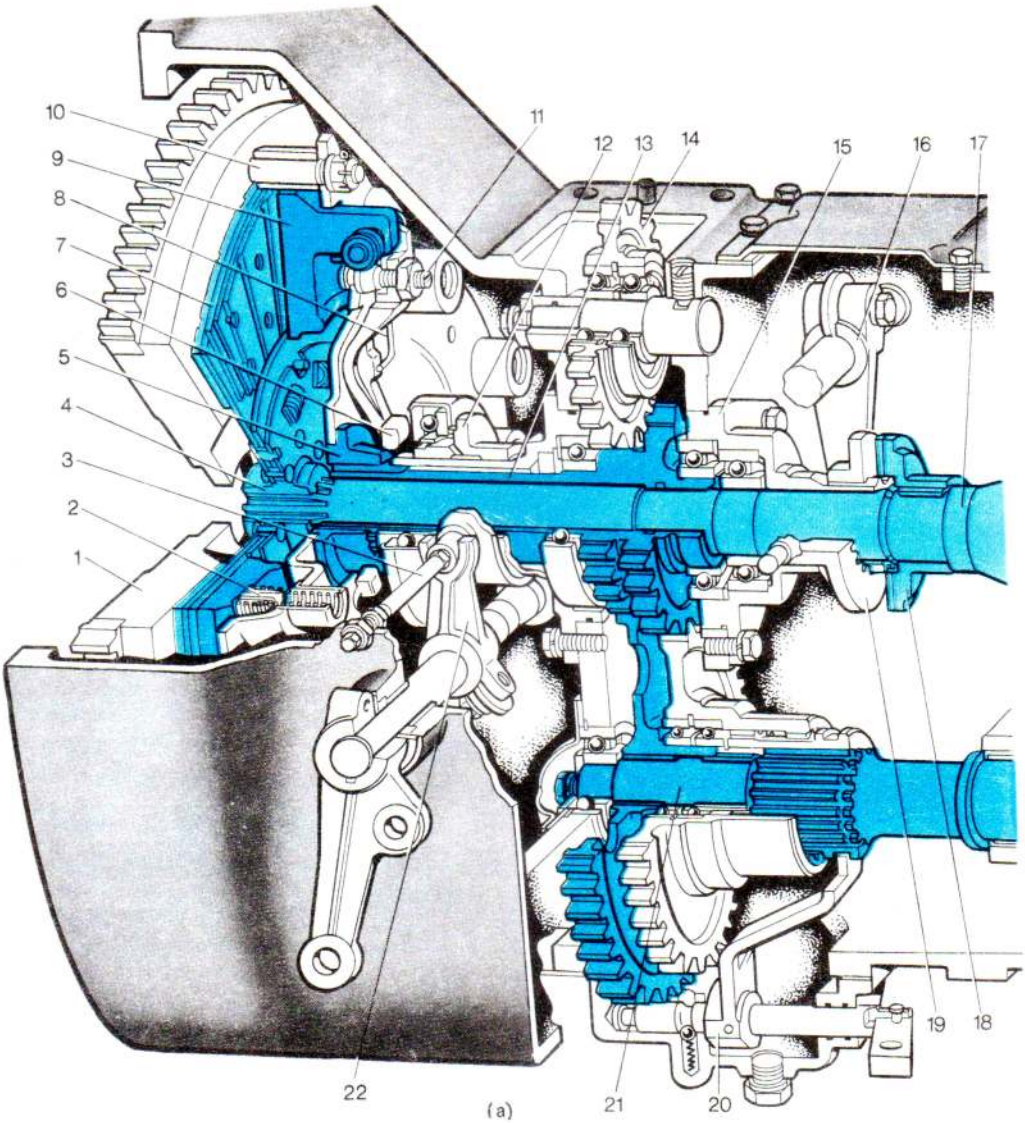
Schematic diagram of a clutch

1 – driving disc (pressure plate);
2 – pressure spring;
3 – driven disc;
4 – flywheel;
5 – release lever;
6 – release bearing;
7 – clutch pedal;
8 – transmission clutch (input) shaft

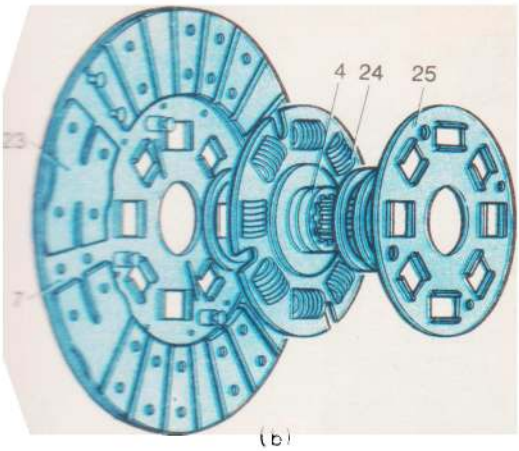




The single-disc clutch of a tractor (Fig. 78) consists of driving and driven components and a release mechanism. The driving part of the clutch includes engine flywheel *1* and pressure plate *9*, and the driven part, driven (friction) disc *7* and transmission input shaft *17*.

The pressure plate is provided with three projections that fit in recesses of clutch back, or cover, plate *8* (also known as the clutch cover) which is fastened to the flywheel by pins *10*. Pivoted to the pressure plate projections are release levers *6*. Twelve pressure springs *2*. which are held in cups between the clutch cover and pressure plates, clamp the driven disc between the flywheel and the pressure plate.

The driven disc consists of hub *4* that is splined to the transmission input shaft and a steel plate, with two friction linings riveted to



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a - Single-disc clutch of the MT 3-80 Model tractor and (b) details of a driven disc

1 - flywheel;
2 - pressure spring;
3 - cover hose;
4 - driven disc hub;
5 - back (cover) plate hub;
6 - release lever;
7 - driven disc;
8 - back (cover) plate (case cover);
9 - pressure plate;
10 - pin;
11 - adjusting screw;
12 - release bearing;
13 - live PTO drive shaft;
14 - hydraulic pump drive gear;
15 - bracket;
16 - clutch brake fork;
17 - transmission input shaft;
18 - clutch brake driving disc;
19 - clutch brake sliding disc;
20 - PTO control mechanism;
21 - PTO shaft;
22 - release fork;
23 - spring plate (cushion spring);
24 - damping spring;
25 - drive washer

the plate on both sides to provide a nonslip drive. The disc contains wavy spring plates *23*, known as the cushion springs, sandwiched between the steel plate and the rear friction lining, so that the initial contact is made by a relatively small area, tending to make the engagement gradual. The driven disc plate is connected to the hub by a series of damping springs *24* arranged in a circle around the hub. The springs take out some initial engagement shock and tend to minimize torsional vibration which is inherent in piston-type engines because of the periodically alternating power strokes. Some clutches use rubber damping elements instead of the damping springs.

When the clutch is engaged and the engine running, the pressure springs squeeze the driven disc between the pressure plate and the flywheel, causing the entire mechanism to revolve as a unit. When the driver depresses the clutch pedal, the clutch linkage compresses the pressure springs, relieving pressure on the driven disc, which allows it to turn free. In this position, no power is transmitted through the clutch, and the transmission gears can be shifted without difficulty.

The clutch is equipped with a brake whose purpose is to stop quickly the transmission input shaft in order to decrease wear on the end faces of transmission gear teeth in shifting. Clutch brake driving disc *18*, with a friction lining adhesion-bonded to it, is rigidly mounted on the transmission input shaft. Sliding disc *19* of the brake is splined to stationary bracket *15*. The operating mechanism of the clutch brake is interlocked with that of the clutch. As the clutch is disengaged, the sliding disc of the clutch brake is pressed against the driving disc, and the transmission shaft is thus braked.

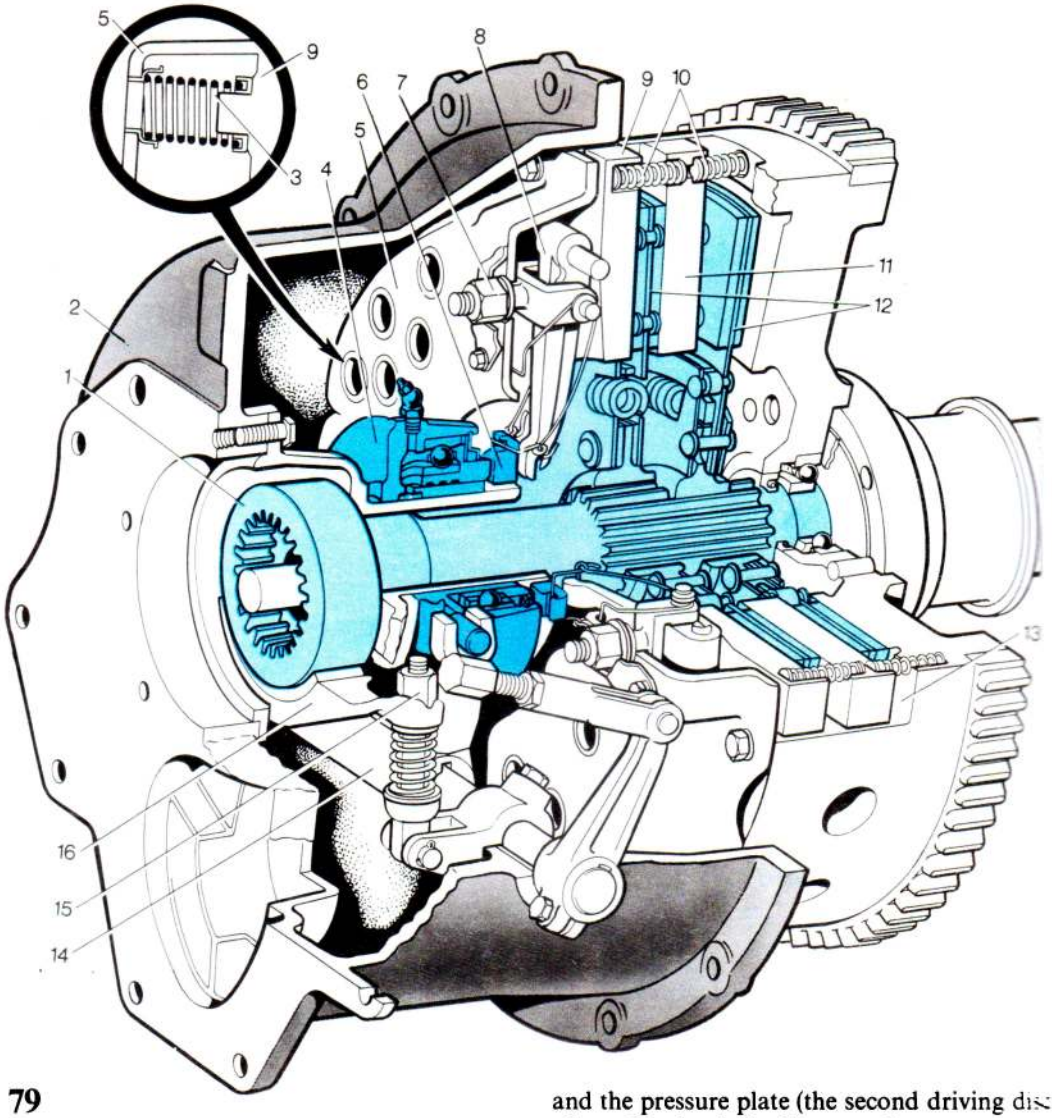
Splined to cover plate hub *5* is hollow drive shaft *13* of a live (constant-running, or independent) PTO. The shaft is made integral with two gears which provide two power takeoff speeds – 540 rpm and 1000 rpm. PTO control mechanism *20* is mounted in the lower part of the clutch housing.

Automobile clutches are of similar construction, but have no clutch brake or PTO shaft drive.

The size of automotive clutches depends on the outside diameter of the driven disc, which is determined by the maximum torque developed by the engine.

10.2. Double-Disc Clutch

As its name implies, the double-disc clutch (Fig. 79) has two driving and two driven discs arranged in alternate order. On each side of the intermediate disc (the first driving disc nearest to the flywheel), there are four release springs that hold the disc midway between the flywheel



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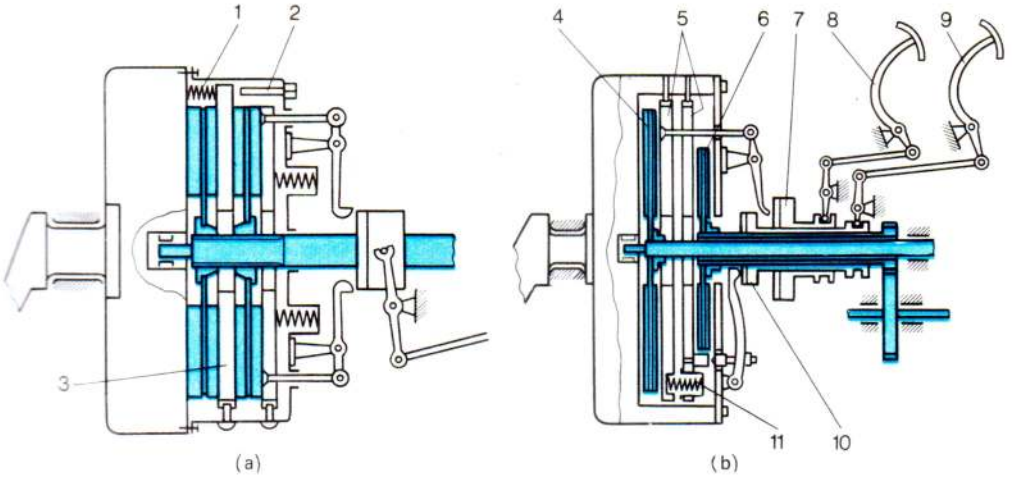
Double-disc clutch of the T-150K Model tractor

1 – shaft;
2 – housing;
3 – pressure spring;
4 – release bearing;
5 – cover;
6 – release collar (sleeve);
7 – adjusting nut;
8 – release lever;
9 – pressure plate;
10 – release spring;
11 – intermediate disc;
12 – driven discs;
13 – flywheel recess;
14 – release fork;
15 – clutch brake adjusting nut;
16 – clutch brake shoe

and the pressure plate (the second driving disc when the clutch is disengaged.

The hubs of the driven (friction) discs are splined to the clutch shaft. The front end of the shaft is supported by a ball bearing carried in a bore in the flywheel end face, while the rear end is splined to the transmission input shaft and is supported by its front bearing.

The clutch driven discs are clamped between the end faces of the flywheel, intermediate disc and pressure plate by a series of coil pressure



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Schematic diagrams of (a) simple and (b) dual double-disc clutches

1 – release spring;
2 – adjusting screw;
3 – intermediate driving disc;
4 – transmission clutch driven disc;
5 – driving discs;
6 – PTO clutch driven disc;
7 – transmission clutch release bearing;
8 and 9 – transmission and PTO clutch pedals;
10 – PTO clutch release bearing;
11 – pressure spring

springs held between the pressure plate and the clutch cover.

The release levers are pivoted in yokes that are fastened to the clutch cover by nuts 7. The outer ends of the release levers are pivoted to the pressure plate, and the inner ends are connected with release collar 6. The release bearing is actuated by release fork *14* which is linked with the clutch pedal by a system of levers and rods.

When the clutch pedal is depressed, release bearing *4* forces the release collar together with the inner ends of release levers *8* inward (to the right in Fig. 79), which causes the outer ends of the release levers to move pressure plate *9* to the left, compressing the pressure springs. As the pressure plate is moved away from the flywheel, release springs *10* force the intermediate disc to occupy an intermediate position between the flywheel and the pressure plate, thus relieving pressure on the driven discs. In this position no power can be transmitted through the clutch.

The clutch is provided with a brake whose main part is shoe *16* lined with a friction material. One end of the brake shoe is pivoted to the clutch housing and the other is connected through a spring with an actuating lever held to the clutch release fork shaft, so that when the clutch is disengaged, the shoe is pressed against the clutch shaft to brake it.

In some double-disc clutches, release springs are used only on one side of the intermediate driving disc, and the outward movement of the disc is limited by adjusting screws *2* (Fig. 80*a*).

Double-disc clutches may be of a simple or a dual (combination) type. *The dual clutch* not only provides the means of connecting the engine to the transmission of a tractor, but also provides power from the engine to a live power takeoff shaft. The clutch (Fig. 80*b*) is a combination of two clutches, one of which transmits the drive from the engine to the transmission input shaft and the other transmits the drive to the PTO shaft. The clutches have independent driven discs *4* or *6* and independent driving discs (pressure plates) *5*, but share common pressure springs *11*. The clutches also have independent shafts, one being placed inside the other, and are operated by independent linkages.

10.3. Clutch Release Mechanisms

The clutch release mechanism may be actuated either mechanically or pneumatically. *A mechanically operated clutch release mechanism* (Fig. 81*a*) consists of a clutch pedal, a release bearing, and a linkage to carry the movement of the clutch pedal to the release bearing. When clutch pedal *1* is pushed down, the linkage pushes release bearing *4* forward (to the left in Fig. 81*a*). As the release bearing moves left, it pushes against the inner ends of release levers *3* whose outer ends move the clutch pressure plate away from the flywheel, releasing the driven disc, and the clutch is thus disengaged. When disengaging the clutch, the movement of lever *6* is transmitted through a rod to clutch brake lever *5* to brake the transmission input shaft.

To engage the clutch, the clutch pedal is released. This action takes the pressure off the release bearing, allowing the pressure springs to squeeze the driven disc between the flywheel and the pressure plate. There must be sufficient free play in the linkage to keep the release bearing from touching the release levers when the clutch is engaged. Without this play, the release bearing would contact the levers and apply some pressure which would tend to weaken the spring pressure on the pressure plate, allowing the clutch driven disc to slip. The resulting frictional heat would soon destroy the clutch completely.

To lessen the effort required to depress the clutch pedal, the clutch release mechanisms on many tractors are equipped with boosters. In the clutch release mechanism considered here, the booster takes the form of spring *10* pushing against fulcrum pin *9* screwed in bracket *8*. As the clutch pedal is depressed, the spring first is compressed and then expands, aiding in disengaging the clutch fully.

In some tractors, the clutch pedal effort is reduced with the aid of a *pneumatic servomechanism*. The mechanism (Fig. 81*b*) consists of air actuator *12* mounted on the left side of the clutch housing and a follow-up device. The body of the device is connected to the clutch pedal through the medium of rod *7*, while its plunger *15* is connected to lever *6*. When the clutch pedal is depressed, compressed air from the tractor air system flows through valve *14* to the air actuator and forces rod *11* to actuate the clutch release bearing and disengage the clutch. As the clutch pedal is released, a clearance appears between valve *14* and plunger *15*, and compressed air leaves the actuator chamber through the follow-up device.

10.4. Clutch Troubles

Most common clutch troubles are incomplete engagement and incomplete disengagement.

Incomplete engagement (the clutch slips while engaged) could be caused by an incorrect linkage adjustment (no clearance between the release bearing and release levers), oil on the linings of the friction disc, worn friction disc linings, or weakening of the pressure springs. In this case, the tractor or automobile "pulls" poorly, and burnt friction linings can be smelled in the driver's cab.

Incomplete disengagement (the clutch spins or drags when disengaged) may result from an incorrect linkage adjustment (excessive clearance between the release bearing and release levers). Or, this could be due to internal clutch troubles, such as linings torn or loose from the friction disc, a warped friction disc or pressure plate, improper clutch adjustment (nonuniform clearance between the release bearing and release levers), or binding of the friction disc hub on the transmission input shaft. In this case, the transmission gears will be difficult to shift and will clash and grind when shifting.

Internal clutch troubles call for overhauling the clutch mechanism. However, if the trouble is in the linkage – if it is binding or out of adjustment – the linkage can be lubricated and readjusted.

CLUTCH MECHANISM AND LINKAGE ADJUSTMENT. During operation, the friction linings of the driven disc, or discs, and the friction surfaces of the flywheel and pressure plate suffer wear. As a result, the initial setting of the clutch mechanism and linkage is gradu-

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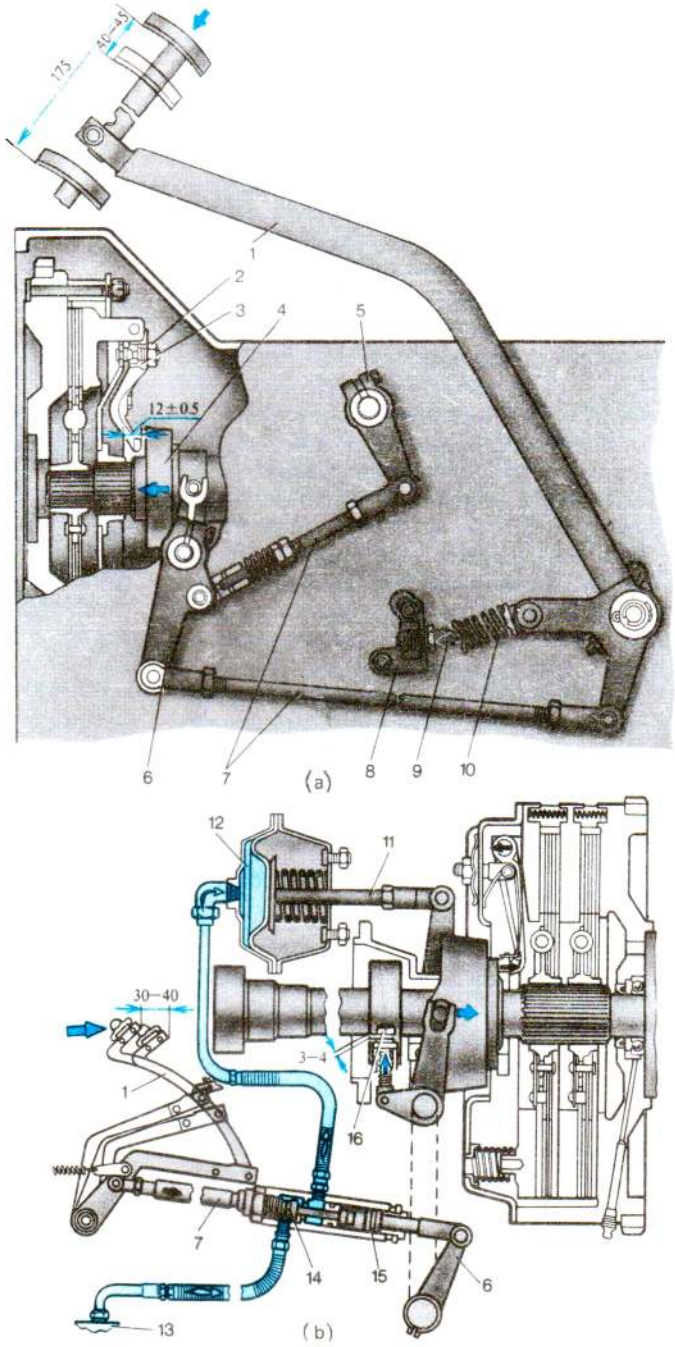
Clutch release mechanisms

a) mechanically operated;
b) pneumatically (air-) operated:
1 – pedal;
2 – adjusting screw;
3 – release lever;
4 – release bearing;
5 – clutch brake lever;
6 – clutch lever;
7 – control rods;
8 – bracket;
9 – fulcrum pin;
10 – spring;
11 – rod.
12 – air actuator;
13 – air-storage tank;
14 – valve;
15 – plunger;
16 – clutch brake adjusting screw



ally disturbed, with the clutch pedal free play diminishing progressively. The free play is the amount of clutch pedal free travel before the clutch begins to disengage, and it must be sufficient for the release bearing to stay clear of the release levers when the clutch is engaged. Unequal clearances between the individual release levers and the release bearing may cause the pressure plate to skew, disturbing normal clutch operation (the clutch may drag when disengaged or chatter while engaging).

The free play of the clutch pedal is adjusted by varying the length of operating rod *7* (Fig. 81*a*). If the clutch is equipped with a brake, brake operating rod *7* should be removed before making the adjustment. Also, the clutch pedal should be relieved of the booster spring pressure, if a booster is used, by screwing in fulcrum pin *9* as far as it will go.

The clutch brake, if one is used, is adjusted after the clutch pedal free play is adjusted properly. This is done by varying the length of brake operating rod *7* or by changing the position of the brake shoe with the aid of adjusting nut *16*. The brake should be adjusted so as to ensure that it is applied only after the clutch is completely disengaged.

The release levers are adjusted by means of adjusting screws *2*, their lock nuts being loosened beforehand. This adjustment is usually made when overhauling the clutch mechanism.

When operating the tractor or automobile, keep in mind that the clutch should be disengaged quickly and engaged only gradually. A sudden clutch engagement may cause damage to transmission components. Never "ride" the clutch pedal, by resting a foot on the pedal, for this partly releases the clutch, causing clutch slippage and rapid wear of the clutch disc friction surfaces.

Review Questions

1. What are the units the drive line of an automobile consists of?
2. List the drive-line units of a crawler tractor.
3. Where can friction be used to advantage?
4. What is the purpose of the clutch?
5. Show in Fig. 78 the driving and driven parts of the clutch.
6. What is the difference between the simple and dual double-disc clutches?
7. What kinds of clutch operating mechanism do you know?
8. List the most common clutch troubles.
9. How is the clutch adjusted?

Chapter 11
Transmissions

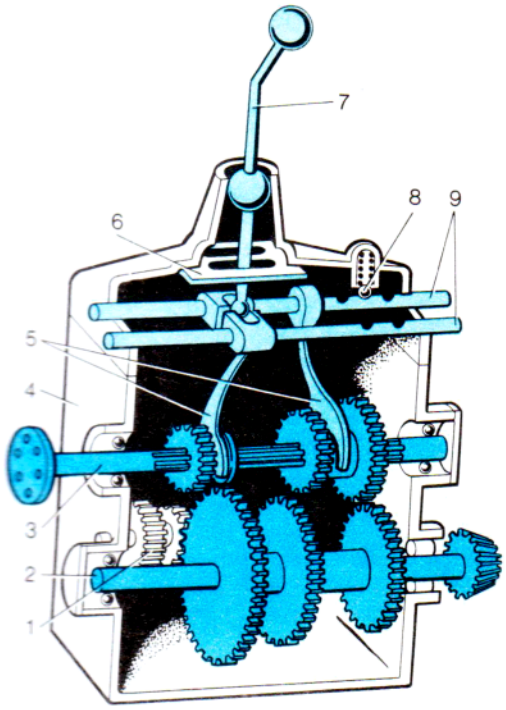
11.1. General

The transmission serves the purpose of changing the engine torque and speed into the torque and speed required by the wheels of the tractor or automobile for each task. It also provides a means of allowing the tractor or automobile to be reversed when required and allows the drive to the wheels to be stopped without having to stop the engine or keep the foot applied to the clutch pedal.

The transmission operates on the principle of reducing the engine speed, before the drive from the engine crankshaft is applied to the driving wheels of the tractor or automobile, through the use of suitable pairs of meshing gears, the speed ratio between the crankshaft and the wheels being selectable in a number of steps. The *speed ratio*, also known as the gear ratio, is the ratio of the speed of the driving element of a mechanism to the speed of the driven element and in the case of meshing gears, it is expressed as the ratio of the number of teeth on the driven gear to the number of teeth on the driving gear. If the drive is transmitted through several pairs of gears, the total speed ratio of the drive train is found by multiplying the speed ratios of all the individual pairs of gears in the train.

At the same time, the transmission increases the engine torque, for when speed is lost through gears, torque is gained in the same proportion.

So, with the engine speed remaining the same, the running speed of the tractor or



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Schematic diagram of a transmission

1 – reverse idler cluster gear; 2 – output (main) shaft; 3 – input (drive) shaft; 4 – case; 5 – gear shift forks; 6 – gear shift gate (quadrant); 7 – gear shift lever; 8 – gear shifter shaft lock; 9 – gear shifter shafts (selector bars)

automobile can be changed by shifting the transmission gears to change the speed ratio between the engine crankshaft and the drive wheels or sprockets.

Figure 82 illustrates a simple transmission having three forward speeds and one reverse speed. Meshing the smallest gear splined on to input (drive) shaft *3* with the biggest gear carried on output (main) shaft *2* provides low (1st) gear. The sliding gears splined on to the input shaft are shifted into and out of mesh with the gears on the output shaft by operating gear shift lever *7* which actuates gear shift forks *5*. The forks move together with gear shifter shafts, or selector bars, *9*, or slide along them as along guides. Gear shifter shaft locks *8* serve to lock the meshed gears in position and prevent them from parting on their own. To prevent the shifting of more than one gear at a time, use is made of gear shift gate, or quadrant, *6*.

It is advisable to operate the tractor or automobile in the highest possible gear, for the higher the transmission gear, the higher the fuel economy and the efficiency of the power train. Therefore, the greater the number of the available gear ratios in the transmission, the more fully the engine power can be used in conditions of varying load.

Fixed-ratio transmissions are classified in several types according to the following characteristic features:

(a) number of shafts – two-, three-, and four-shaft types;

(b) arrangement of shafts relative to the longitudinal axis of the vehicle – longitudinal- and transverse-shaft types;

(c) manner in which gears are meshed – sliding- and constant-mesh types;

(d) conditions required for shifting gears – stop-and-shift and on-the-go shift (power shift) types;

(e) shifting method – manually shifted, hydraulically shifted, and automatic (self-shifting) types;

(f) number of available forward-speed ratios – two-speed, three-speed, four-speed. etc. types;

(g) number of sliding gears – two-, three- and four-shifter types;

(h) structural design – unit construction and built-in types.

The speed ratios provided by tractor transmissions may be arbitrarily divided into three groups: main, transport, and low.

Main speed ratios provide for tractor land speeds required by the majority of field tasks. For modern tractors, these speeds range from 1.4 to 4.2 m/s (5 to 15 km/h).

Transport speed ratios are used in carrying goods by tractor-trailer combinations and also in ferry trips. In wheeled tractors, these speed ratios provide for land speeds in the range 4.2 to 9.5 m/s and in crawler tractors, 4.2 m/s.

Low speed ratios provide for tractor land speeds required by some field tasks, such as transplanting and root-crop harvesting. These speeds are in the range 0.4 to 0.16 m/s.

Automobile transmissions have a smaller number of speeds, the scope of work of the automobile being much narrower than that of the tractor.

The low speed ratios provided by automobile transmissions are used for starting away from rest and accelerating, and also for negotiating difficult road sections.

High speed ratios are used when cruising under good road conditions.

Automobile transmissions have only one reverse speed, which is used for manoeuvring, whereas tractor transmissions may have several reverse speeds, since the tractor runs in reverse not only when manoeuvring, but also when carrying out various operations, e.g., when teaming the tractor with drags or rakes. Some tractors can be reversed in any gear.

11.2. Automobile Transmissions

The number of speed ratios required of automobile transmissions being not very great, the gear-train arrangements of such transmissions are relatively simple.

The supporting structure of the automobile transmission (Fig. 83) is formed by case *10* and cover *5*. Supported by ball bearings inside the transmission case are three shafts: transmission drive gear shaft (clutch, or input, shaft) *1*, transmission main, or output, shaft *8*, and transmission countershaft, or layshaft, *11*.

The transmission drive gear shaft is made integral with transmission drive gear *2* and tooth rim *3*. The front end of the shaft is supported by a ball bearing installed in the central bore in the flywheel end face and the rear end is supported by a ball bearing in the front wall of the transmission case.

The transmission main shaft is splined and carries sliding gears that can be moved along the splines. The front end of the shaft is supported by a roller bearing housed in a bore in the end face of the transmission drive gear shaft and the other end is supported by a bearing mounted in the rear wall of the transmission case. Both shafts are thus arranged coaxially.

The transmission countershaft carries a series of gears differing in diameter. The gears are fabricated in the form of a cluster and rigidly fixed to the shaft. Front gear *12*, called the countershaft driven gear, is in constant mesh with transmission drive gear, and so the transmission countershaft and all its gears always rotate with the transmission drive gear shaft, but in the opposite direction.

Reverse idler gear *9* is made in the form of a twin-gear cluster that is freely supported on a shaft by a plain bronze bushing press-fitted in the gear. The reverse idler gear shaft is held fast in holes drilled in the transmission case walls.

The gear shift mechanism is carried in the transmission case cover. Sliding gears *6* and *7* are moved along the transmission main shaft by gear shift forks that freely fit in grooves cut in their respective gears. The forks are rigidly connected to their respective gear shifter shafts (selector bars), so that when the shafts are moved by the lower end of gear shift lever *4*, the forks must also move. The central part of the gear shift lever is supported by a fulcrum ball that fits in a hemispherical socket in the transmission case cover.

The transmission described above has four forward gears, or speeds, and one reverse gear. First gear is provided by moving first-and-second-speed cluster gear *7* backwards along the transmission main shaft to mesh the gear with the countershaft low (1st) gear. To shift into second gear, the cluster gear is moved forward to mesh with the countershaft second gear. Third gear is engaged by shifting third-and-fourth-speed gear *6* backward to mesh it with the countershaft third gear. When the gears are shifted into fourth, the two gears on the transmission main shaft (i.e., gears *6* and *7*) are demeshed from the countershaft gears. Also, the third-and-fourth-speed gear is forced axially against the transmission drive gear whose tooth rim *3* meshes with internal teeth in the third-and-fourth-speed gear. This locks the transmission drive gear and main shafts as one, so that the drive from the engine

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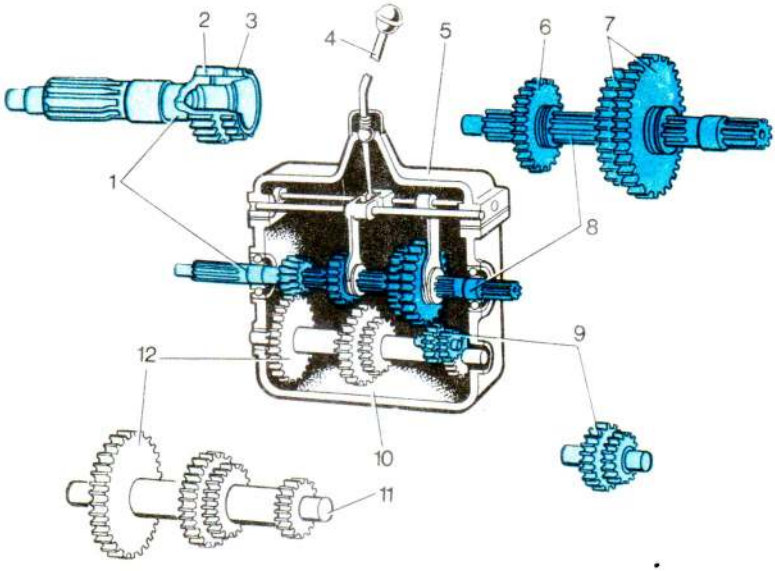
Automobile transmission

1 – drive gear shaft;
2 – drive gear (clutch gear);
3 – tooth rim;
4 – gear shift lever;
5 – case cover;
6 – third-and-fourth-speed gear;
7 – first-and-second-speed gear;
8 – main shaft;
9 – reverse idler cluster gear;
10 – case;
11 – countershaft;
12 – countershaft driven gear (constant-mesh gear)

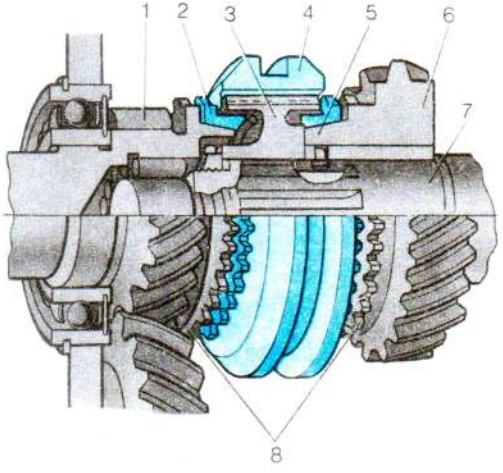


crankshaft is transmitted directly to the transmission main shaft. When reverse gear is required, reverse idler cluster gear 9 is slid along its shaft to mesh with the first-speed gears on the transmission main shaft and countershaft. When shifting into reverse, the driver has to overcome the resistance of a safety spring arranged in the engaging lug of the reverse gear shifter shaft. This excludes the possibility of an unintentional shift into reverse on the go.

To eliminate the clushing of the transmission gears and make shifting into high gears easier, modern automobile transmissions are equipped with inertia-type synchronizers (synchromesh devices) that synchronize the rotation of the gears which are about to be meshed. This makes gear-shifting noiseless.

In the automobile four-speed transmission using a high-gear synchronizer, the third-speed gear is in constant mesh with the countershaft third gear and supported by a bushing on a plain portion of the transmission main shaft. To reduce noise, the constant-mesh gears in the transmission are made with helical (twisted) teeth. They run more quietly than spur gears and distribute the torque load over a larger area of each tooth.

THE SYNCHRONIZER (Fig. 84) consists of hub



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Transmission synchronizer

1 – transmission drive gear;
2 – synchronizer (blocking) ring;
3 – synchronizer hub;
4 – synchronizer sleeve;
5 – synchronizing cone;
6 – third-speed gear;
7 – main shaft;
8 – tooth rims on transmission gears

3, sleeve 4 with internal teeth, and two conical synchronizer, or blocking, rings 2. The hub has internal splines and external teeth. Transmission drive gear 1 and third-speed gear 6 are provided with tooth rims 8 and synchronizing cones 5 that face the synchronizer. To shift into third gear, synchronizer sleeve 4 is moved by its shift fork backward (to the right in Fig. 84) to mesh with tooth rim 8 on the third-speed gear. Moving the synchronizer sleeve forward to mesh it with the tooth rim on the transmission drive gear provides fourth gear (direct drive). When the synchronizer sleeve is moved in either direction, the sleeve, acting through spring-loaded keys (not shown in the figure), pushes in front of itself one of the synchronizer rings 2 until the conical surface of the ring contacts the synchronizing cone on the corresponding transmission gear. When contact is made, the rotational speeds of the gear and the synchronizer sleeve are equalized, thanks to friction between the conical surfaces. Now, further movement of the shift lever moves the synchronizer sleeve into mesh with the tooth rim of the gear without making any noise.

11.3. Stop-and-Shift Type Tractor Transmissions

Consider as an example a nine-speed LONGITUDINAL-SHAFT TYPE TRANSMISSION (Fig. 85). It consists of case 1, drive shaft 4, countershaft 3, main shaft 15, a reverse shaft, a gear shift mechanism, and gears. The transmission case, cast in iron, is of a unit construction type. The transmission drive shaft and countershaft are arranged coaxially. The housing of the main shaft rear roller bearing is installed in the rear wall of the transmission case. Shims 14 are used between the flange of the bearing housing and the transmission case wall to adjust the axial play in the main shaft roller bearings. Transmission main shaft 15 is made integral with transmission lst-stage driven gear 10 whose internal teeth serve to provide 9th gear (direct drive). Splined fast on to the transmission main shaft are the transmission 2nd-stage driven gear and the main drive bevel

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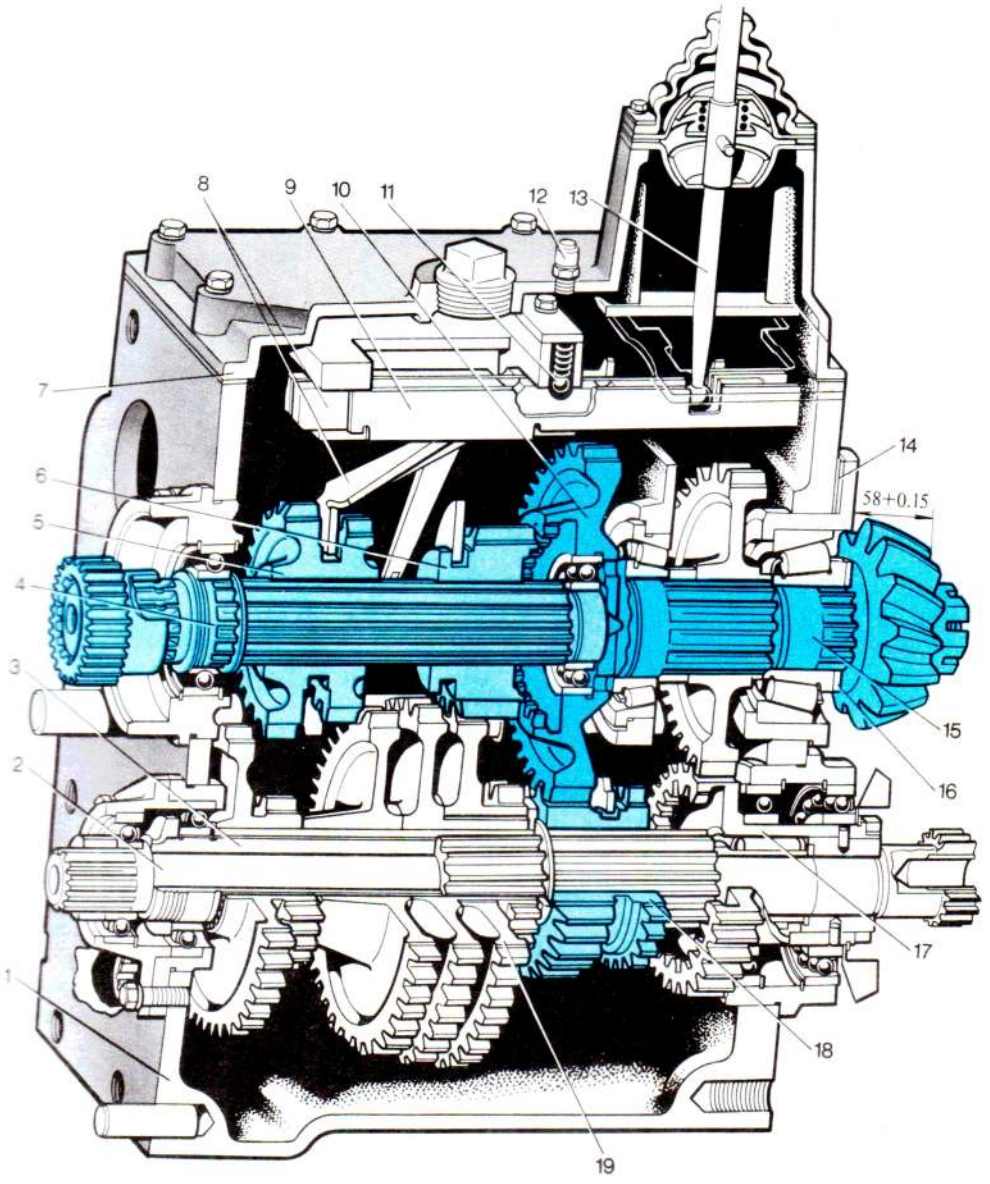
Tractor transmission

1 – case;
2 – independent PTO drive shaft;
3 – countershaft;
4 – drive gear shaft;
5 – 4th-and-5th- (7th-and-8th-) speed sliding gear;
6 – 3rd-4th-and-9th-speed sliding gear;
7 – case cover;
8 – selector bar and fork;
9 – locking plate;
10 – 1st-stage driven gear;
11 – selector bar lock;
12 – breather;
13 – gear shift lever;
14 – adjusting shims;
15 – main shaft;
16 – washer;
17 – 2nd-stage drive gear;
18 – 1st-and-2nd-stage sliding gear;
19 – twin-gear cluster

pinion. Washer 16 serves to adjust the position of the main drive pinion relative to the transmission case rear end face. Pressed in the central bore in the transmission main shaft front end face is a bearing that serves to support the transmission drive shaft rear end.

The transmission countershaft is hollow and accommodates independent (live) PTO drive shaft 2. Splined on to the transmission countershaft are a series of gears. The first four gears (counted in the direction from the front to the rear of the tractor) are held fast to the shaft by a snap ring. The 5th and 6th gears are made in the form of twin-gear cluster 19 that is arranged to rotate freely on the hub of the 4th gear. The 7th and 8th gears form twin-gear cluster (sliding gear) 18 that can be slid along the splines of the shaft. Moving the cluster gear forward (to the left in Fig. 85) engages the first stage of the transmission. To engage the second transmission stage, cluster gear 18 should be moved backwards. The transmission first stage provides for 1st, 3rd, 4th, and 5th forward-speed ratios and 1st reverse-speed ratio, while the rest of the speed ratios are provided by the transmission second stage. The transmission second stage uses gear 17 with internal and external teeth. The hollow gear hub projects from the transmission case and is provided with splines on the outside for synchronous PTO drive. The hub houses a needle bearing that serves as a rear support for the transmission countershaft. The hub itself is supported by two ball bearings installed in



a housing that fits in a bore in the transmission case rear wall.

Splined on to the transmission drive shaft are two sliding gears. Moving sliding cluster gear 5 forward provides either 5th or 8th gear (speed ratio), according as 1st or 2nd transmission stage is engaged. Moving the gear backward provides 4th or 7th gear.

Rear sliding gear 6 can occupy one of the following three positions: forward, central, and backward. Moving the gear into the forward position provides 3rd or 6th gear, while moving

it backwards provides 9th gear (direct drive). With the gear in the central position, the drive is transmitted to gear *10* (Fig. 86) splined to reverse shaft *11* located on the left side of the transmission case. The shaft carries sliding gear *12*. Moving the gear backward (to the right in Fig. 86) provides 1st or 2nd forward-speed ratio, whereas moving it forward provides all the reverse-speed ratios.

Reverse idler gear *13* revolves on a stationary spindle and is in constant mesh with the smaller gear of the first twin-gear cluster carried on transmission countershaft *8*.

The gear shift mechanism consists of gear shift lever *13* (Fig. 85), selector bars *8* with forks, locking plates *9*, and selector bar locks *11*. Each selector fork shifts only one sliding gear and is welded to its selector bar. The shifter fork of high-low range shift clutch *3* (Fig. 86) is connected to its shifter bar by a shifter arm and a shaft.

Locking plates *9* (Fig. 85) prevent the gear shift lever from moving more than one selector bar at a time, i. e., prevent simultaneous shifting of several gears. Spring-loaded ball-type locks *11* prevent unintentional movement of the selector bars, hence of the sliding gears.

Tractors of recent models are equipped with an interlocking system which allows the tractor engine to be started only when the gear shift lever is in neutral. The system includes a switch which is installed in the transmission case cover and arranged to ground the magneto ignition system of the starting engine or break the starter motor circuit whenever the gear shift lever is moved from neutral to shift into any gear.

The transmission considered here is provided with an additional speed reduction gear set used for shifting from a high-speed to a low-speed range or vice versa and may also be equipped, as an option, with a creeper gear.

THE HIGH-LOW RANGE SHIFT is accommodated in the clutch housing in front of the transmission case and allows any speed ratio provided by the transmission to be reduced by a factor of 1.3. It includes drive gear *1* and driven gear *4* (Fig. 86), each provided with a tooth rim, toothed shift clutch *3*, and

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Transmission of the MT3-80 Model tractor (with longitudinal arrangement of shafts)

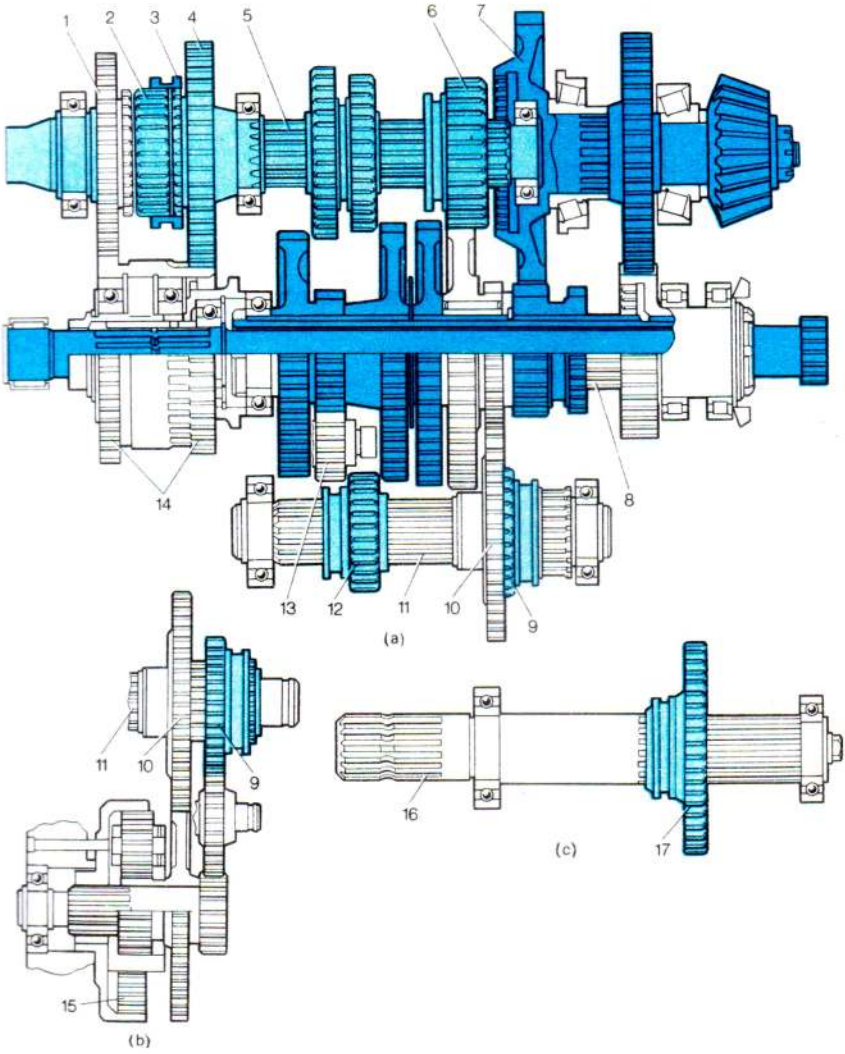
(a) main gears;
(b) creeper gear;
(c) side PTO drive;
1 – high-low range shift drive gear;
2 – clutch shaft;
3 – toothed clutch;
4 – high-low range shift driven gear;
5 – transmission drive shaft;
6 – drive shaft sliding gear;
7 – main shaft gear;
8 – transmission countershaft;
9 – creeper gear set drive sliding gear;
10 – first-and-second-speed (forward and reverse driven gear;
11 – reverse shaft;
12 – 1st-2nd-and-reverse-speed sliding gear;
13 – reverse idler gear;
14 – high-low range shift intermediate cluster gear
15 – creeper gear set;
16 – side PTO shaft;
17 – side PTO drive gear

intermediate cluster gear *14*. Shifting into low range is effected by moving shift clutch *3* forward to mesh with the tooth rim of drive gear *1*. Thus, the high-low range shift doubles the number of speed ratios provided by the transmission.

CREEPER GEAR SET *15* is housed in a separate case and may be installed in place of the left-hand side cover of the transmission case. It is a planetary gear set used to reduce 1st and 2nd forward- and reverse-speed ratios, and so it is driven from reverse shaft *11*. The creeper gear is engaged by moving sliding gear *9* backwards. In this case, gear *9* is the driving gear of the creeper gear set, with gear *10* serving as its driven gear. To prevent accidents, one should bear in mind that with the creeper gear engaged, the tractor moves backward in forward gears and forward in reverse gears.

If necessary, side PTO shaft *16* may be installed in place of the creeper gear on the left-hand side of the transmission case. In four-wheel drive row-crop tractors, a transfer case is installed in place of the right-hand side cover of the transmission case. The drive for the transfer gear set is provided by gear *7*.

On some tractors, the creeper gear set is housed in a separate case that is mounted on the front wall of the transmission case. The creeper gear is used only with the transmission in one of the main low gears to further reduce

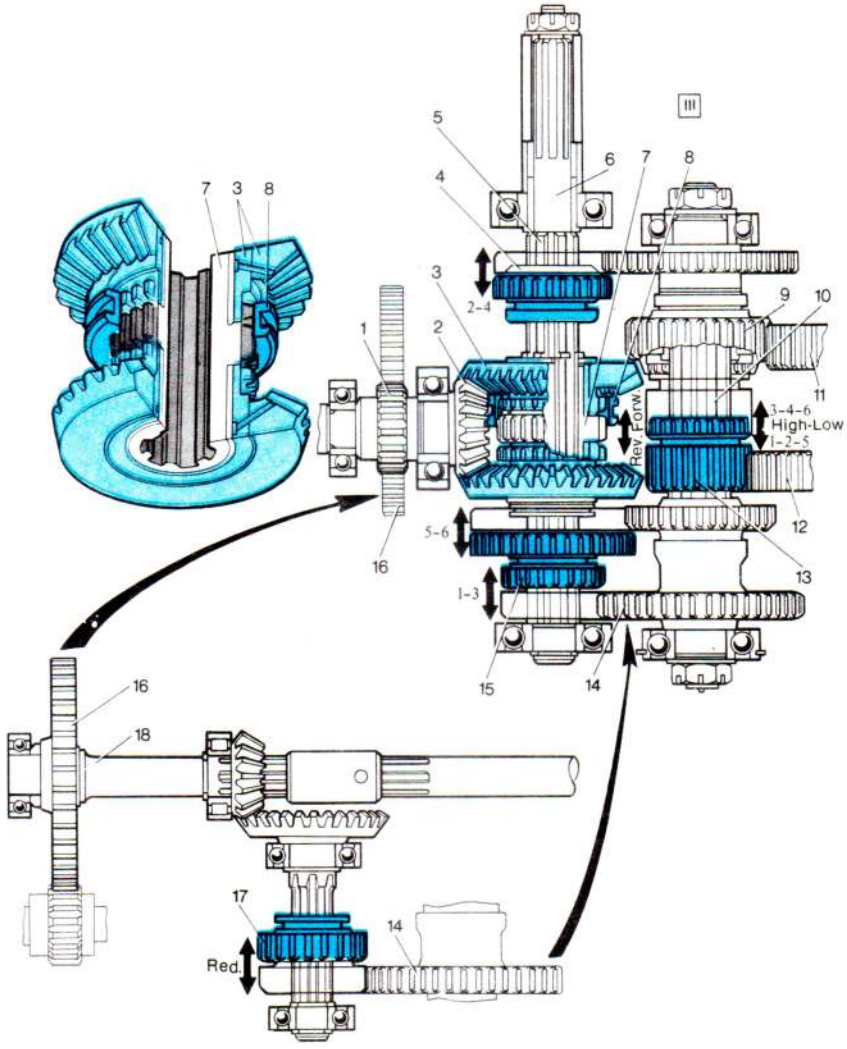


the land speed of the tractor and not to increase its drawbar pull, for this may cause damage to the transmission mechanisms.

Some row-crop tractors are equipped with

A TRANSVERSE-SHAFT TYPE TRANSMISSION

(Fig. 87). The transverse arrangement of the transmission shafts makes the transmission case shorter, which allows the transmission to be made integral with the differential. A specific feature of this type of transmission is the



possibility of shifting from forward to reverse or vice versa in any gear. This is accomplished by means of a reverser gear set comprising two bevel gears that are freely mounted on transmission countershaft *5* and are in constant mesh with transmission main drive bevel pinion *2*. Each of the gears can be individually locked to the transmission countershaft by reverser

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Transmission of the T-25A Model tractor with transverse arrangement of shafts)

1 – PTO drive gear;
2 – transmission main drive bevel pinion;
3 – reverser right-hand bevel gear (forward-speeds ratios);
4 – 2nd-and-4th-speed sliding gear
5 – transmission countershaft;
6 – external shaft end for belt pulley;
7 – toothed sleeve;
8 – reverser toothed clutch;
9 – 3rd-4th-6th-and-2nd-reduced-speed gear;
10 – transmission main shaft;
11 – differential ring gear (3rd, 4th, 6th, and 2nd reduced speed ratios);
12 – differential ring gear (1st, 2nd, 5th, and 1st reduced speed ratios);
13 – high-low range shift sliding gear;
14 – 1st-3rd-and-1st-and-2nd-reduced-speed gear;
15 – 5th-6th-and-1st-2nd-3rd-speed sliding gear;
16 – PTO driven gear;
17 – reduced-speed sliding gear;
18 – PTO shaft

toothed clutch *8*. Since the gears revolve in opposite directions, locking one of them to the countershaft will provide forward-speed ratios, whereas locking the other one to the shaft will give reverse-speed ratios. In our case, forward-speed ratios are provided by moving clutch *8* to the right to lock right-hand bevel gear *3* to the countershaft.

The transmission countershaft carries two sliding gears *4* and *15* that are splined on to the shaft. Moving these gears to mesh with their respective gears on transmission main shaft *10* provides three speed ratios. This number of speed ratios is doubled to obtain a total of six speed ratios by means of a low-high range shift comprising gears *9*, *11*, *12*, and *13*, gears *11* and *12* doubling as the differential ring gears. Gear *9* is free to rotate on the transmission main shaft and is in constant mesh with differential ring gear *11*. Sliding gear *13* is splined on to the transmission main shaft and can occupy two positions: a left-hand position, in which it meshes with differential ring gear *12*, and a right-hand position wherein it meshes with internal teeth in gear *9* to lock the gear to the transmission main shaft.

The transmission also has an additional reduced-speed ratio, which, considering the high-low range shift, makes the transmission have eight speed ratios in all. The power flow in this gear is from PTO drive gear *1* to transmission main shaft gear *14* through PTO shaft *18* and sliding gear *17*.

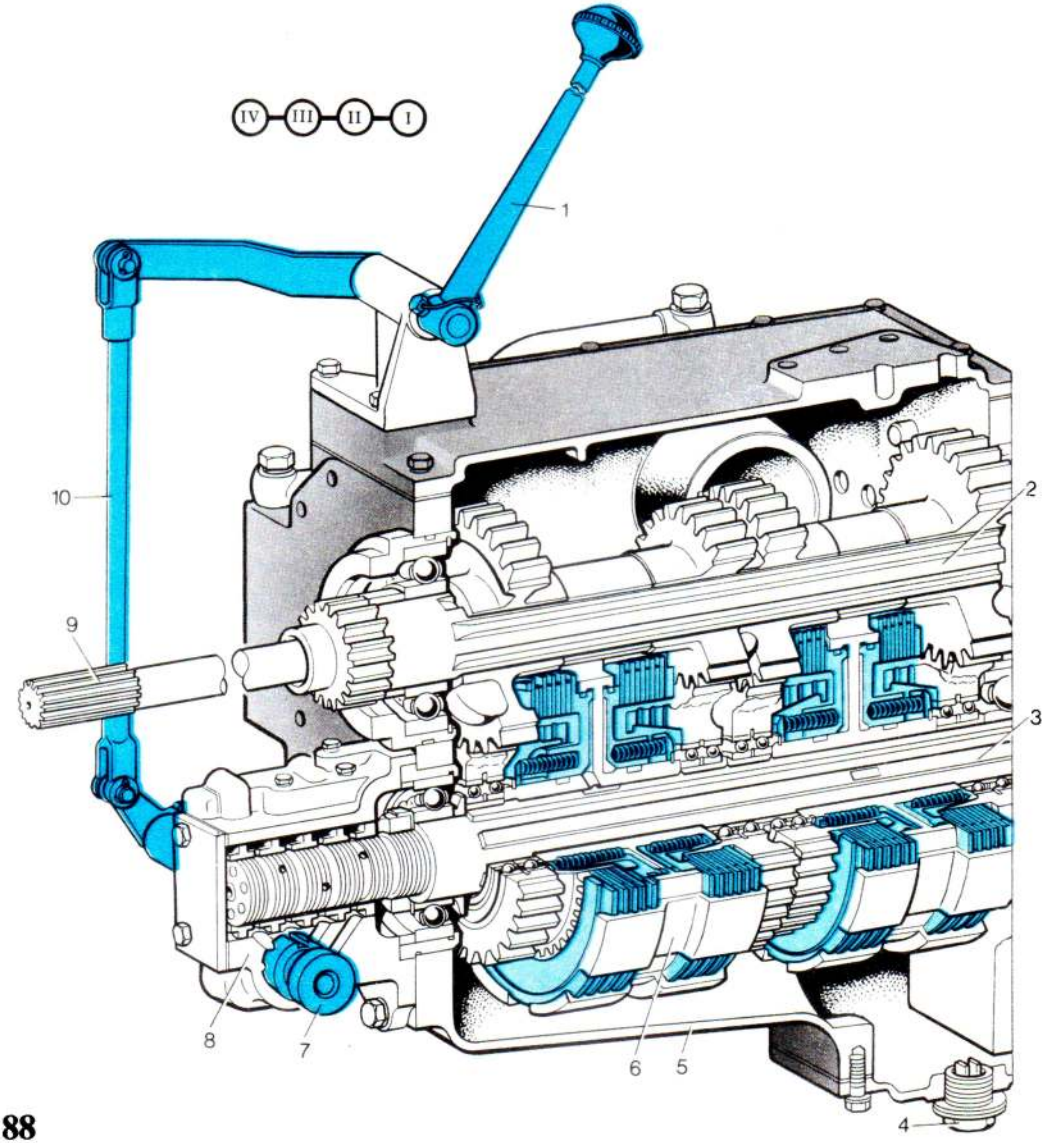
11.4. On-the-Go (Power) Shift Type Tractor Transmissions

Modern tractor designs embody the latest developments in the tractor industries of this and other countries. One such development is a transmission that can be shifted to any gear while power is being transmitted. Such a transmission is referred to as an on-the-go, or power, shift transmission. In some tractors, this takes the form of a hydraulically controlled plain gear transmission whose speed ratio is changed in steps, as in the ordinary transmissions considered above, by a series of hydraulically controlled clutches that can be engaged and disengaged under power.

The transmission (Fig. 88) consists of case *5* which houses input shaft *2* and output shaft *3*. Both shafts are supported by ball bearings whose housings fit in bores in the transmission case walls. Rigidly splined to the input shaft are 4th- 1st-, 2nd-, and 3rd-speed drive gears (from left to right in Fig. 88). All the input shaft gears are in constant mesh with their respective driven gears carried on the output shaft. All the output shaft gears are supported by ball bearings and arranged so as to transmit the drive to the output shaft only through hydraulically controlled clutches *6*.

Each clutch comprises a set of driving and driven discs which are normally free to rotate relative to one another, i. e., they do not connect the output shaft gears to the shaft. To transmit the drive, the clutch discs are squeezed together by the pressure of hydraulic fluid (engine oil Grade M10Г or M10B in summer and Grade M8Г in winter). Oil is delivered to the clutches individually, via four passages drilled in the transmission output shaft. There is also a central (fifth) passage in the shaft, through which lubricating oil is supplied to the friction elements of the clutches.

Mounted on the front wall of the transmission case is hydraulic control (selector)



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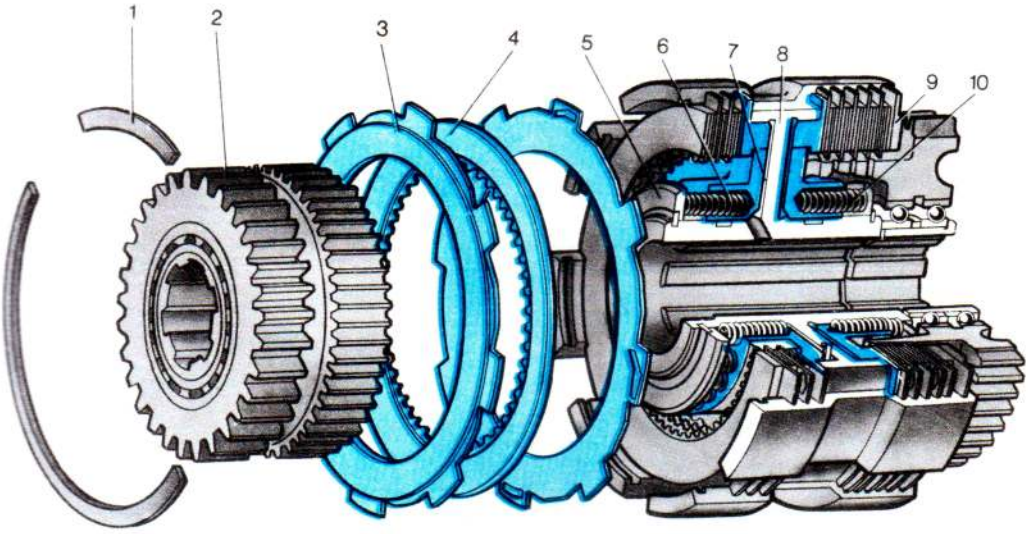
Transmission of the T-150K Model tractor (with hydraulic control)

1 – control (gear shift) lever;
2 – input shaft;
3 – output shaft;
4 – drain plug;
5 – transmission case;
6 – hydraulically controlled clutch;
7 – rotary valve;
8 – hydraulic control (selector) valve;
9 – PTO drive shaft;
10 – control valve linkage

valve *8* that serves to direct oil pressure to the proper clutch. Rotary valve *7* of the control valve assembly is actuated by control (gear shift) lever *1* that is operated by the driver to select one of the four speed ratios provided by the transmission.

THE HYDRAULICALLY CONTROLLED CLUTCHES (Fig. 89) are arranged in pairs in two drums splined to the transmission output shaft.



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Hydraulically controlled clutches

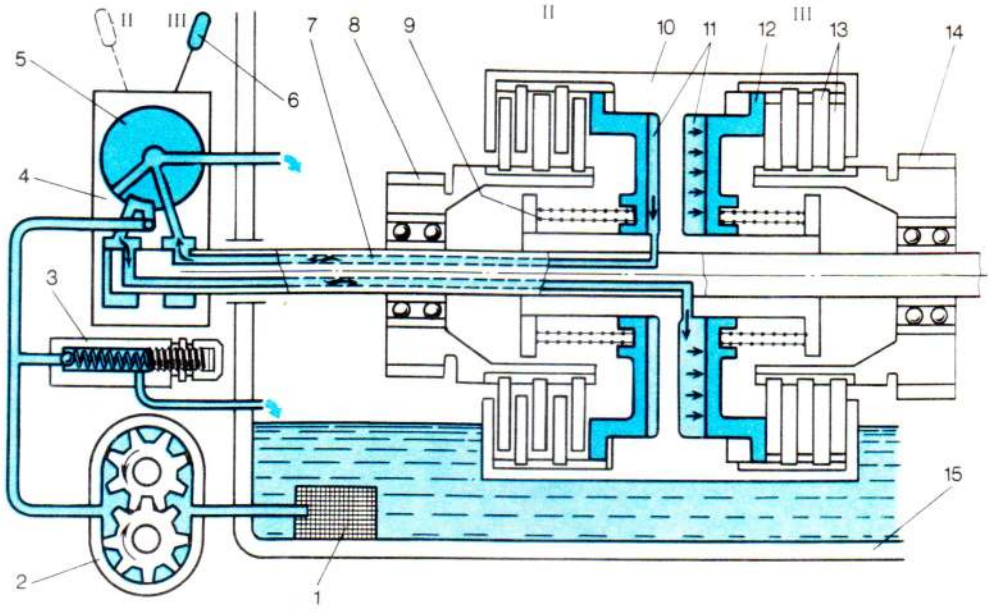
1 – lock ring;
2 – transmission gear;
3 – driven disc;
4 – driving disc;
5 – thrust ring;
6 – piston;
7 – cavity;
8 – drum;
9 – cover plate;
10 – release spring

Inside each drum *8*, there are annular cavities accommodating clutch pistons *6*. The pistons are sealed in their cavities by cast-iron piston rings on the outside and rubber sealing rings on the inside. The drums are provided with slots into which fit external projections of steel driven discs *3*. There are five such discs in the first- and the second-speed clutches, and four discs in the third- and the fourth-speed clutches. Sandwiched between the driven discs are driving discs *4* faced with a cermet material. The driving discs are splined to their respective transmission gears *2*. Each stack of driven and driving clutch discs is held in place in the drum by cover plate *9* and lock ring *1* that is grooved in the clutch drum. Another groove in the drum accommodates thrust ring *5*. Clamped between the thrust ring and the clutch piston are clutch release springs *10*.

The clutches are controlled by means of a hydraulic transmission control system.

THE HYDRAULIC TRANSMISSION CONTROL SYSTEM (Fig. 90) creates and maintains at a certain level the oil pressure required to control the operation of the transmission clutches and directs this pressure to the proper clutch, as determined by the position of the control (gear shift) lever. It also cools the transmission components. The system includes hydraulic pump *2*, hydraulic control (selector) valve *4*, and relief valve *3*. These component parts are mounted on the transmission case which also doubles as an oil reservoir. There are also oil filters, a hydraulic accumulator used to maintain the necessary oil pressure in the transmission clutches when shifting gears, an oil tank and oil cooler installed in the front part of the tractor, and oil lines.

The hydraulic transmission control system operates as follows. Suppose the gear shift lever is operated to place the gears in third. Oil pump *2* draws oil from the transmission case and forces it to hydraulic control valve *4* whence it is directed through a passage in transmission output shaft *7* into annular cavity *11* in the right-hand clutch that is hermetically sealed by clutch piston *12*. Oil pressure forces the clutch



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Schematic diagram of a hydraulic transmission control system

1 – intake filter;
2 – hydraulic pump;
3 – relief valve;
4 – hydraulic control (selector) valve;
5 – rotary valve;
6 – control (gear shift) lever;
7 – output shaft;
8 – second-speed driven gear;
9 – release springs;
10 – drum;
11 – cavity;
12 – clutch piston;
13 – driving and driven discs;
14 – third-speed driven gear;
15 – transmission case

piston to the right. As the piston moves right, it squeezes the stack of driving and driven discs *13*, so that rotation is transmitted from third-speed driven gear *14* to the transmission output shaft. At the same time, release springs *9* force the piston of the second-speed clutch to move to the right, releasing the clutch discs and expelling the oil from the clutch cavity and into the transmission case through hydraulic control valve *4*, so that second-speed driven gear *8* is disconnected from the transmission output shaft.

Hydraulic gear shifting allows the transmission gear ratio to be changed under power and reduces harmful dynamic loads on the transmission components.

11.5. Transfer Cases

The number of speed ratios provided by the power shift transmission considered above can be increased by using additional gears arranged in what is known as the transfer case. The transfer case is a power-train unit intended primarily to transmit power to the front driving wheels of a tractor or automobile. In our case, the unit is fastened to the rear wall of the transmission case which in turn is assembled to the clutch housing and the engine, the whole assembly being mounted on the tractor frame by means of bearer brackets and rubber blocks.

THE TRANSFER CASE (Fig. 91) includes front- and rear-axle drive shafts, a PTO drive shaft, and a series of gears.

Sliding toothed clutch *8* is splined on to fixed toothed coupling *17* that is rigidly connected to the transmission output shaft. High-

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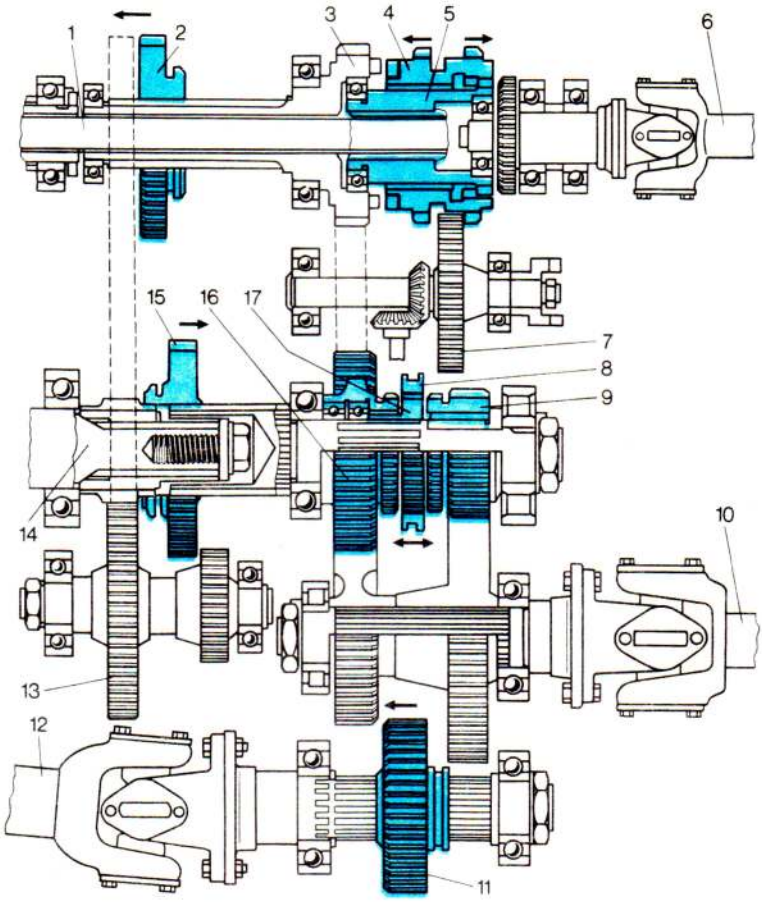
Transfer case (T-150K wheel tractor)

1 - PTO drive shaft;
2 - reverse gear;
3 - gear
4 - sliding twin-gear cluster;
5 - splined sleeve;
6 - PTO shaft;
7 - hydraulic pump drive gear
8 - sliding toothed clutch;
9 - low- (working-) speed-range drive gear;
10 - rear-axle cardan shaft;
11 - front drive sliding gear;
12 - front-axle cardan shaft;
13 - intermediate gear set driven gear
14 - input shaft;
15 - intermediate gear set sliding gear
16 - high- (transport-) speed-range drive gear;
17 - fixed toothed coupling



transport-) speed-range drive gear *16* and low-working-) speed-range drive gear *9* are free to rotate on their shaft. Both gears are made integral with tooth rims with which the sliding toothed clutch can be made to mesh to lock either gear to the transmission output shaft. Thus, shifting from the high-speed range to the low-speed range or vice versa doubles the number of speed ratios provided by the transmission. The high- and low-speed-range drive gears transmit rotation through their respective driven gears to the rear- and front-axle drive shafts. The front-axle drive shaft can be disconnected from the transmission by moving front drive sliding gear *11* backwards (to the right in Fig. 91).

The transfer case also accommodates PTO shifter and hydraulic pump drive gears. PTO drive shaft *1* is placed inside the hollow transmission input shaft. The front end of the PTO drive shaft is rigidly connected with the engine crankshaft and its other end is connected to splined sleeve *5* that is supported by ball bearings. Splined on to the sleeve is sliding twin-gear cluster *4*.

With sliding gear *4* in its central (neutral) position, the drive from the engine crankshaft is transmitted only to hydraulic pump drive gear

7. When the sliding gear is moved backward, its internal teeth mesh with the teeth of the PTO drive gear to engage PTO shaft *6* without interrupting the flow of power to the hydraulic pump drive gear. If the sliding gear is moved forward, it will demesh from splined sleeve *5* and, at the same time, the dogs on the front end face of the gear will connect it to gear *3* which will transmit the drive to the hydraulic pump from the land wheels of the tractor. Driving the hydraulic pump from the tractor land wheels enables the hydraulic transmission control and hydraulic servo steering systems to operate while the tractor is being towed.

To allow the tractor to be used with power takeoff combines and some other farm machines, provision is made in the transmission for a creeper gear set. It provides eight additional reduced speed ratios. The creeper gear set is arranged in the transmission case and is engaged by moving sliding gear *15* backwards. When the sliding gear is in its forward position, its internal teeth lock the input shaft of the transfer case to the transmission output shaft.

To place the gears in reverse, sliding reverse gear *2* in the transmission case is moved forward. In this position, the gear transmits rotation from creeper gear set driven gear *13* to high-speed-range drive gear *16*, via gear *3*.

THE GEAR SHIFT MECHANISM (Fig. 92) of this transmission consists of control (shifter) levers, shifter shafts with forks, a gate (quadrant), an interlocking shaft, and shifter shaft locks.

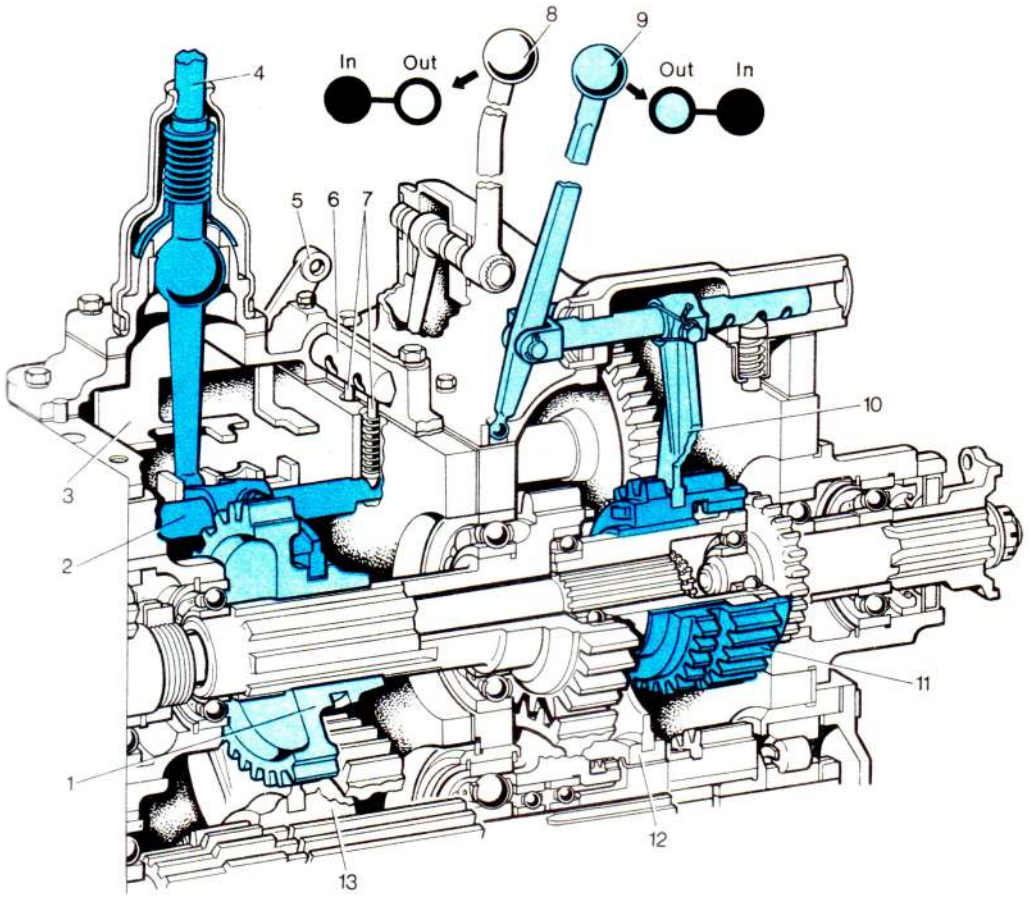
In the driver's cab, there is speed-range selector, reverse, and creeper gear shifter lever *4* that is arranged in front of the driver, beside the gear shift lever operating the transmission hydraulic control valve. At the driver's side and above the transfer case are PTO shifter lever *9* and front drive shifter lever *8*. Shifter shafts *2* that connect the levers with the shift forks are locked in both engaged and disengaged positions by spring-loaded lock plungers *7* that fit into matching recesses in the shafts.

Gear shift gate *3* prevents shifting more than one gear at a time. To exclude unintentional shifting, use is made of an interlocking device. Interlocking shaft *6* has three shallow radial holes and is connected to the clutch pedal linkage by means of lever *5* and a rod. With the clutch pedal fully depressed, the interlocking shaft is turned so that its holes are facing shifter shaft lock plungers *7*. Now, moving any gear shifter shaft to shift the gears causes its associated lock plunger to lift and enter its respective hole in the interlocking shaft. When the gear shift is completed, the spring pressure on the lock plunger forces the plunger to leave the hole in the interlocking shaft and enter the recess in the gear shifter shaft to lock it in the engaged position. As the clutch pedal is released to engage the clutch, the interlocking shaft is turned so that its holes are moved away from the lock plungers of the gear shifter shafts. Now, the cylindrical surface of the interlocking shaft prevents the lock plungers from leaving their recesses in the gear shifter shafts, and so no shaft can be moved. Thus, the interlocking device does not allow the gears to be shifted unless the clutch is disengaged completely.

THE TRANSFER CASE (Fig. 93) used to transmit power to the front driving wheels of a row-crop tractor is fastened to a side wall of the transmission case of the tractor. With this transfer case, the front-wheel drive is automatically engaged whenever the slipping of the tractor rear wheels reaches 5 to 6%.

The transfer case is a single-stage reducing unit equipped with a roller-type free-wheeling clutch. The case houses transfer gear shaft *10* supported by two ball bearings. Splined on to the shaft are free-wheeling clutch inner race *7*, sliding clutch lock gear *8*, and universal-joint flange *9* of the front axle propeller shaft.

The transfer case gear, made integral with free-wheeling clutch outer race *5*, is in constant mesh with idler gear *4* which in turn is in constant mesh with transmission main shaft gear *3*. The outer race of the free-wheeling clutch is supported by two ball bearings mounted on the inner race, and so it can rotate relative to the latter. The outer race is provided with shaped recesses that house jam rollers *6*. The speed of outer race *5* that is driven from the tractor transmission is always proportional to the speed of the tractor rear wheels, whereas the speed of inner race *7* that is rigidly connected to



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Gear shift mechanism T-150K Model tractor)

1 – reverse gear;
2 – gear shifter shaft (selector bar);
3 – gear shift gate (quadrant);
4 – speed-range selector, reverse, and creeper gear shifter lever;
5 – interlocking shaft lever;
6 – interlocking shaft;
7 – gear shifter shaft lock plunger;
8 – front drive shifter lever;
9 – PTO shifter lever;
10 – shift fork;
11 – hydraulic pump drive gear;
12 – toothed clutch;
13 – creeper gear set sliding gear

shaft *10* is proportional to the speed of the tractor front driving wheels. The front- and rear-axle ratios are selected so that the inner race rotates approximately 6% faster than the outer race. Therefore, when the tractor operates in good road conditions, i.e., when the tractor rear wheels do not slip, no power is transmitted to the front wheels.

As the rear wheels start slipping, their rotational speed increases, while the land speed of the tractor, hence the rotational speed of the front wheels, decreases. As a result, the rotational speed of the outer race of the free-wheeling clutch is increased and that of the inner race is decreased. When the speeds of the clutch outer and inner races become equal, rollers *6* jam in their recesses in the outer race, thus locking it to the inner race. The whole mechanism starts rotating as a unit, transmitting torgue from the tractor transmission to the front driving wheels. Once

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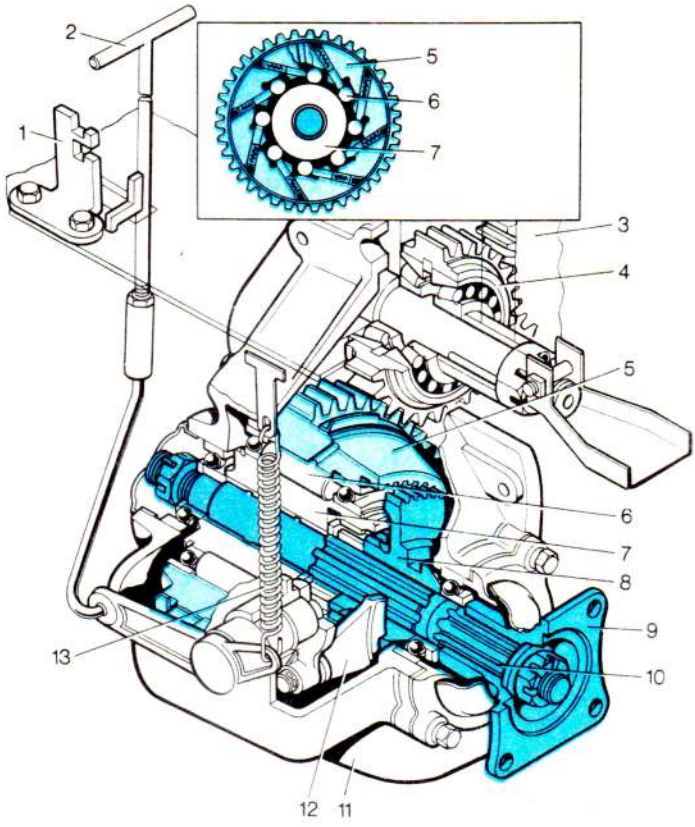
Transfer case (MT3-52 Model tractor)

1 – locking plate;
2 – front drive shifter lever;
3 – transmission main shaft gear;
4 – idler gear;
5 – free-wheeling clutch outer race;
6 – rollers;
7 – free-wheeling clutch inner race;
8 – sliding clutch lock gear;
9 – universal-joint flange;
10 – transfer gear shaft;
11 – case;
12 – shifter fork;
13 – spring



the rear wheels cease slipping, the front driving axle is automatically disengaged.

Whenever it becomes necessary to overcome heavy draft resistances (e. g., when running in reverse, starting away from rest, or negotiating road obstructions), the front driving axle can be engaged intentionally, by operating front drive shifter lever *2* to mesh sliding clutch lock gear *8* with the internal teeth in the clutch outer race. Locking plate *1* is used to lock the lever in the engaged position. When the lever is released, spring *13* returns the sliding gear to its initial position, thus disengaging the front driving axle.

The transfer case components are lubricated with oil contained in the transmission case.

11.6. Shaft Couplings and Cardan (Universal-Joint) Drives

Shaft couplings and cardan (universal-joint) drives are used to transmit torque between individual power-train units that are located some distance apart.

SHAFT COUPLINGS, as the term implies, serve the purpose of transmitting torgue from one shaft to another, the shaft axes being not necessarily aligned. On tractors, shaft couplings are usually used between the clutch shaft and the transmission input shaft.

According to the number of joints in the coupling, shaft couplings are divided into single and double universal types. As to their

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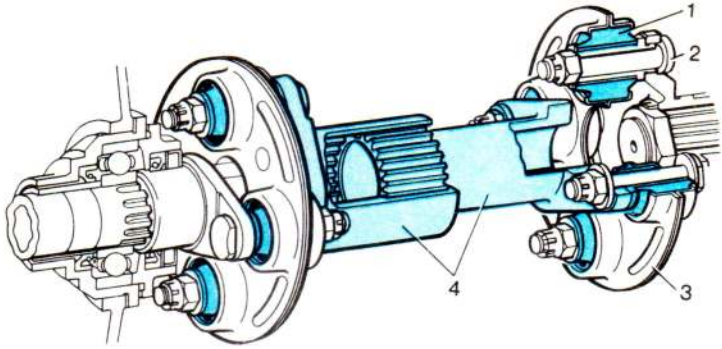
Shaft coupling (ДТ-75М Model tractor)

1 – rubber bushing;
2 – connecting bolt;
3 – universal-joint center ring;
4 – universal-joint forks



construction, shaft couplings may be rigid (all-metal) or flexible (using elastic elements, usually of rubber). Tractors use mainly flexible (elastic) shaft couplings. Such couplings are capable of transmitting torque between shafts having as great an angular misalignment as 3°. A flexible double universal shaft coupling (Fig. 94) consists of two flexible universal joints and a built-up telescopic shaft. Each flexible universal joint includes two forks, or yokes, 4 that are arranged in a crisscross fashion and connected to universal-joint center ring *3* by elastic rubber bushings *1*. The center ring is welded from two stamped sheet-metal discs, and the rubber bushings are pressed in four cylindrical sockets formed in the ring. Press-fitted in the bushings are connecting bolts *2*.

The rear universal-joint fork of the shaft coupling is splined to the transmission input shaft and the front fork is splined to the clutch shaft. The forks are held in place by nuts screwed on the threaded ends of the shafts. The central universal-joint forks of the shaft coupling are splined together, so that they can move axially with respect to each other, and thus form the telescopic shaft of the coupling. Both forks are made hollow, and their outer ends are closed by stamped sheet-metal plugs to protect the splined joint against the ingress of dust and moisture.

CARDAN (UNIVERSAL-JOINT) DRIVES (Fig. 95*a* and *b*) are intended for transmitting torque between individual power-train units whose axes can be displaced during operation. Such drives are for the most part used on automobiles and wheeled tractors to connect the transmission output shaft to the transfer case and driving axle shafts.

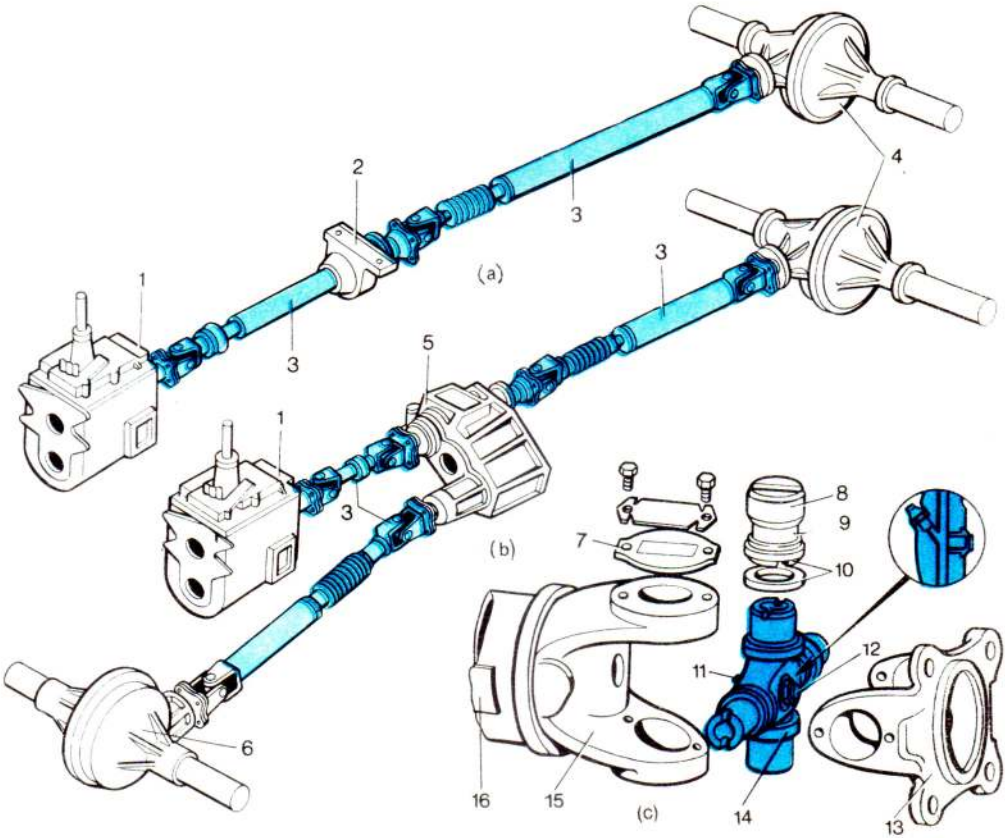
Simple cardan drive *3* consists of one or two universal joints, a shaft, and a slip joint, usually formed by a splined connection between one of the universal-joint forks and the shaft. Universal joints allow the angle of drive to be changed within 24° in any direction, while the slip joint enables the drive to change length.

According to the number of universal joints used in the drive, cardan drives are divided into single-jointed and double-jointed types.

Cardan-drive shafts are usually fabricated from thin-walled steel tubing. Welded to the ends of the tube, called the universal-joint shaft tube, are universal-joint forks (yokes), or a universal-joint fork is welded to one end of the tube and a splined sleeve forming part of the slip joint is welded to the other end of the tube.

To reduce vibration, it is desirable that the drive shaft should have a moderate length. For this reason, where the length of the drive line is large, use is made of two interconnected universal-joint shafts that are supported at their junction by intermediate, or center, bearing *2*. Some four-wheel drive tractors are equipped with a multiple disc slip clutch arranged in the intermediate bearing housing, which serves to prevent overloading the front driving axle in case the rear wheels should slip. The magnitude of torque that the clutch can transmit without slipping is adjusted by varying the spring pressure on the clutch discs.

Tractors and automobiles mostly use cardan drives with rigid-type universal joints (Fig. 95*c*). This type is a double-hinged joint consisting of



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Cardan (universal-joint) drives and cardan (universal) joint

(a) cardan drive of a two-wheel drive automobile;
(b) cardan drive of a four-wheel drive automobile;
(c) rigid-type universal joint;
1 – transmission;
2 – intermediate bearing;
3 – cardan drives;
4 – rear driving axle;
5 – transfer case;
6 – front driving axle;
7 – cover plate;
8 – needle bearing;
9 – needles;
10 – seal ring;
11 – lubricator;
12 – safety valve;
13 and 15 – forks (yokes);
14 – center cross (spider);
16 – cardan shaft balance plate

two Y-shaped forks, or yokes, *13* and *15* that are fixed on the ends of shafts and are hinged to center cross, or spider, *14*. The four arms of the center cross are ground and assembled into needle bearings *8* held in the ends of the two forks by locking plates or snap rings. Seal rings *10* prevent lubricating oil from leaking out of the bearings. The oil is forced into the bearings through lubricator *11* and oil passages in the center cross. The excess oil leaves the joint via safety valve *12* in the center cross.

Cardan drive unbalance causes increased vibration of and additional loads on the drive and associated power-train components. Therefore, each cardan shaft is balanced on a special machine. The unbalance is corrected by means of metal balance plates *16* that are welded to the shaft at places where it lacks in mass.

11.7. Transmission Troubles

Most common transmission troubles are as follows: oil leaks, excessive noise, overheating.

hard shifting into gear, slipping out of gear, and simultaneous shifting of two gears.

Oil will leak from the transmission when the drain plug is loose, sealing gaskets are damaged or loose, or the side-cover bolts are loose. Leakage at the rear of the transmission is caused by wear of the transmission rear seal or the drive line yoke. Oil will leak from the transmission because of foaming resulting from the use of improper lubricant or overfilling. Loose transmission bearing retainer bolts and a cracked transmission case are other causes. Oil leaks are eliminated by tightening up loose fasteners and replacing damaged gaskets and worn seals.

Noise from a transmission in neutral is probably caused by a worn or dry clutch shaft bearing, worn or dry countershaft bearings, worn gears, or too much shaft end play. Causes of noise in the transmission when it is in gear are worn, chipped, or broken gears and synchronizers, worn bearings, and lack of lubricant. The trouble also may be caused by some of the same conditions that make the transmission noisy in neutral. Worn and damaged gears and bearings should be replaced.

The transmission will overheat if the oil level in the transmission case is too low or if the viscosity of the oil used is too low. Thin oil cannot stay on the rubbing components of the transmission, and so the transmission overheats because of inadequate lubrication. The transmission case should be filled up to the level of the overflow hole or the center mark on the oil gauge glass. Thin oil should be replaced with one whose viscosity is adequate to the season.

If shifting into gear is hard, the reason may be that the shaft splines and gear teeth are worn or dented. If so, the dents should be removed and worn components replaced. Another possible cause of this trouble is an interlocking device linkage that is out of adjustment. To adjust the linkage, disconnect the rod that links the interlocking shaft lever with the clutch pedal. Turn the interlocking shaft so as to make its holes face down (the gear shifter shafts are in this case free to move). Depress the clutch pedal fully, adjust the length of the rod, and connect it to the interlocking shaft lever. Also, the shifter fork inside the transmission case might be bent. If so, it should be replaced.

The transmission may slip out of gear as a result of uneven wear of the gear teeth, incomplete engagement of the gears, or wear of the shifter shaft lock balls or plungers. Defective components should be replaced.

Simultaneous shifting of two gears may be caused by worn shifter shaft lock balls or plungers or a broken gear shift gate. Defective components should be replaced.

Proper handling of the transmission is essential to its useful service life. With the stop-and-shift type of tractor transmission, the gears may be shifted only with the clutch fully disengaged, the engine running slow, and the tractor stopped completely. If shifting into gear is hard as a result of the gear teeth meeting end to end, place the gear shift lever in neutral, momentarily engage the clutch to turn the transmission drive gear, and then shift into gear a second time. Operate the gear shift lever smoothly, without jerks.

Review Questions

1. What is the purpose of the transmission?
2. What is the gear ratio?
3. What is the purpose of the gear shift gate?
4. What is the purpose of the gear shifter shaft locks?
5. How are transmissions classified?
6. What is the purpose of the transmission synchronizer?
7. Show in Fig. 86 how to shift from a high-speed range to a low-speed range and how to engage the creeper gear.
8. What is the characteristic feature of the transverse-shaft type of transmission?
9. How does the hydraulically controlled clutch operate?
10. What is the purpose of the transfer case?
11. Describe the automatic operation of the transfer case used to transmit power to the front driving wheels of a row-crop tractor.
12. What is the purpose of the shaft couplings and cardan drives?
13. How is the universal joint constructed?
14. List the most common transmission troubles.

Chapter 12
Driving Axles

12.1. Automobile Driving Axle

The driving axle is one of cross bars supporting a vehicle, on which the driving wheels turn. The driving axle includes a housing, an axle drive, a differential, two axle shafts (half axles), and final drives (if any).

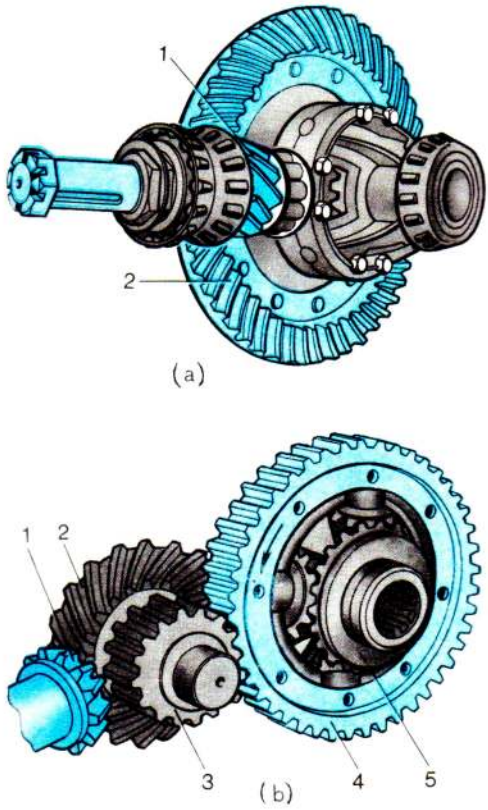
The axle, or main, drive is a drive-line unit that increases the torque delivered by the transmission and transmits it to the driving wheels, via the differential. In automobiles, the axle drive transmits torque at right angles to the drive shaft, usually called the propeller shaft.

The axle drive (Fig. 96) may be a single- or a double-stage type, the former comprising a pair of gears and the latter, two pairs of gears. Drive pinion *1* may be made integral with its shaft, or it may be detachable from the shaft. Driven gears *2* and *4* are usually made in the form of detachable gear rings that are bolted or riveted to the differential case. Axle drive bevel pinions and gears are made with helical teeth in order to reduce noise in operation.

The two-stage axle drive (Fig. 96*b*) consists of a pair of bevel gears and a pair of spur gears. Drive bevel pinion *1* drives bevel gear *2* that is fixed to the flange of the intermediate shaft made integral with 2nd-stage driving spur gear *3*. Gear *3* meshes with driven spur gear *4* which is fastened to the case of differential *5*. The differential case rotates in taper roller bearings installed in the differential carrier that makes part of the driving axle housing.

The differential is a drive-line unit that divides the torque applied to it between the two axle shafts and allows one driving wheel to turn at a different speed from the other.

The differential (Fig. 97*a*) consists of case *1*, cross, or spider, *3*, pinions *4*, and side gears *2*, also known as axle gears. The differential pinions are freely mounted on the cylindrical arms of the spider, which is held in the differential case, and remain in constant mesh with the differential side gears.



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Axle (main) drive

(a) single-stage;
(b) double-stage;
1 – axle drive bevel pinion and shaft;
2 – axle driven bevel gear (differential ring gear);
3 – 2nd-stage driving spur gear and intermediate shaft
4 – driven spur gear (differential ring gear);
5 – differential

When the automobile is moving down a straight and even road, both driving wheels meet with one and the same rolling resistance. In this case (Fig. 97*b*), axle driven gear, or differential ring gear, *5* causes the differential case to rotate. When the differential case rotates, the differential pinions and their spider arms move around in a circle with the differential case. Because the two differential

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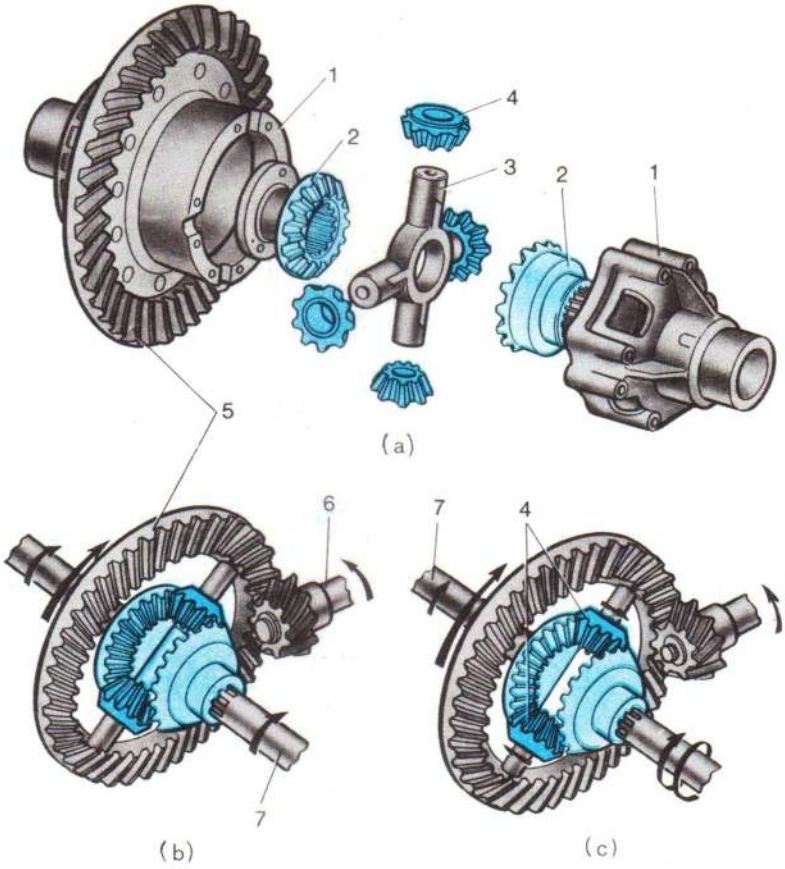
Differential

a – construction;
b – illustrating the operation of the differential on a straightway;
c – illustrating the operation of the differential when rounding a turn;
1 – case;
2 – side gears;
3 – cross (spider);
4 – pinion;
5 – axle driven gear (differential ring gear);
6 – drive shaft;
7 – axle shafts (half axles)



side gears 2 are meshed with the pinions, the side gears must rotáte, causing the axle shafts and their associated driving wheels to turn. With equal resistance applied to each wheel, the differential pinions do not rotate. They apply equal torque to the side gears and therefore both driving wheels rotate at one and the same speed. However, when the resistance to the wheels is unequal, the differential pinions rotate on their spider arms as well as drive round with the differential case. Supposing that one of the axle shafts is prevented from rotating, the differential pinions would have to walk around the stationary side gear, causing the other side gear to rotate at twice its normal speed. You can now see how the differential can allow one driving wheel to turn faster than the other.

Whenever the automobile goes around a turn (Fig. 97*c*), the outer driving wheel travels a greater distance than the inner drive wheel. The inner wheel slows down, while the outer wheel speeds up proportionately, thanks to the differential pinions that rotate on their spider arms and, rolling around the slower side gear, send more rotary motion to the outside wheel.

The differential side gears are splined on to the inner ends of the axle shafts. The other ends of the shafts are attached to the driving wheel hubs by means of flanges. Trucks use full floating axle shafts. Such axle shafts are acted upon by torque only. All the other loads acting on the driving wheels are taken by the driving axle housing, because the wheel hubs are supported by bearings mounted on the housing.

12.2. Driving Axles of General-Purpose Wheeled Tractors

General-purpose wheeled tractors are a four-wheel drive type, i.e., they have two driving axles – front and rear. Both axles are similar in construction, except for the housing. Each driving axle (Fig. 98) consists of a housing, an axle drive, a differential, and final drives. The front- and rear-axle drives are interchangeable and comprise a pair of spiral bevel gears. The

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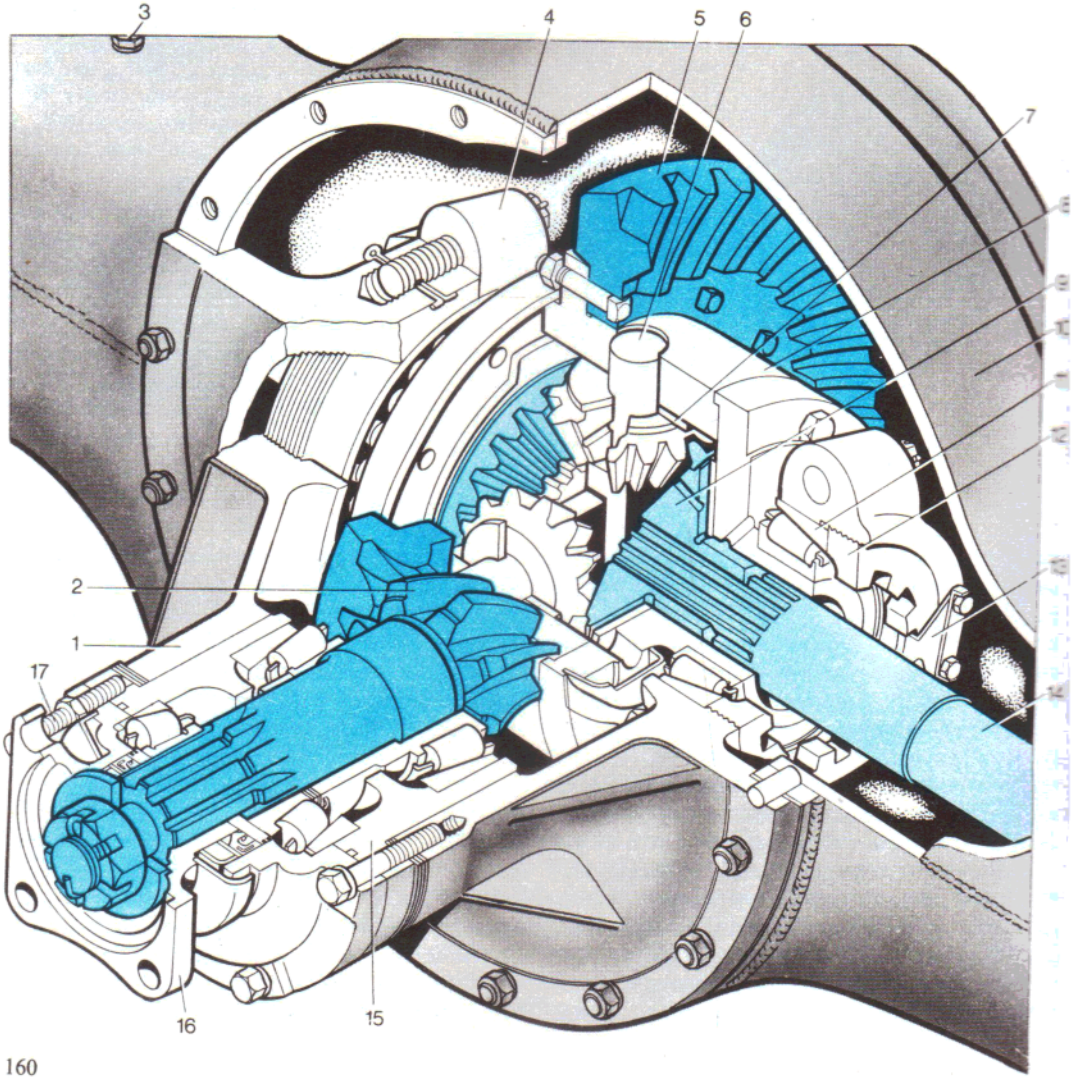
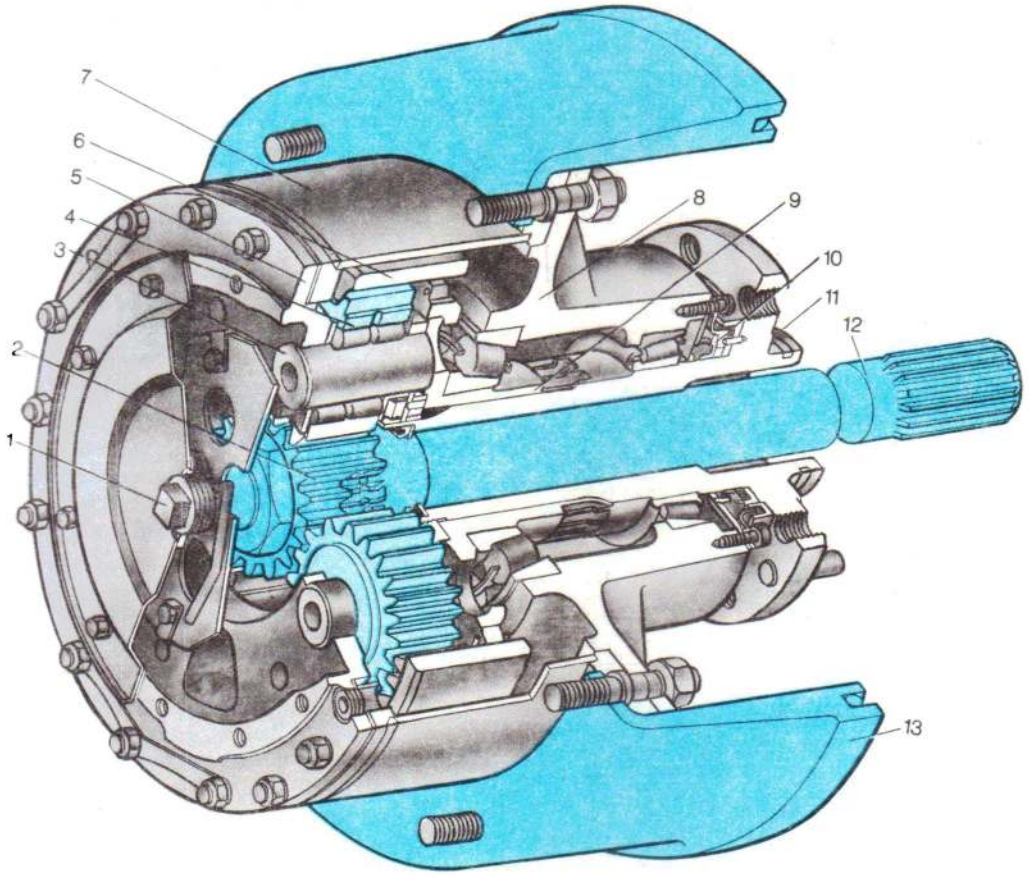
Driving axle of the T-150K Model wheeled tractor

1 – differential carrier;
2 – axle drive pinion;
3 – vent;
4 – bearing cap;
5 – differential ring gear;
6 – pinion shaft;
7 – differential pinion;
8 – differential case;
9 – differential side gear;
10 – driving axle housing;
11 – taper roller bearing;
12 – bearing adjuster nut;
13 – locking plate;
14 – axle shaft;
15 – axle drive pinion carrier;
16 – flange;
17 – puller screw





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Wheel-hub reduction gear of the T-150K Model tractor

1 – plug;
2 – sun gear (wheel);
3 – planet (pinion) gear shaft;
4 – planet (pinion) gear;
5 – planet (pinion) carrier;
6 – internal (ring) gear;
7 – reduction gear housing;
8 – wheel hub;
9 – adapter hub;
10 – seal;
11 – axle shaft housing (axle sleeve);
12 – axle shaft;
13 – driving wheel brake drum

axle drive pinion is made integral with a shaft that is supported by two taper roller bearings installed in axle drive pinion carrier *15*. The latter is accommodated in differential carrier *1* and is fixed to it by bolts. The flange of the axle drive pinion carrier is provided with threaded holes to fit puller screws *17* that are used to remove the axle drive pinion carrier from the differential carrier. The position of the drive pinion relative to the centerline of the axle is adjusted by means of a pack of shims placed under the flange of the drive pinion carrier. Shims placed under the cone of the front bearing are used to adjust the preload on the drive pinion bearings. Splined to front end of the drive pinion shaft is universal-joint flange *16*. The axle drive gear (differential ring gear) is bolted to the differential case flange.

THE DIFFERENTIAL consists of case *8*, four pinions *7*, and two side gears *9*. The differential case comprises two halves that are bolted together and supported by taper roller bearings

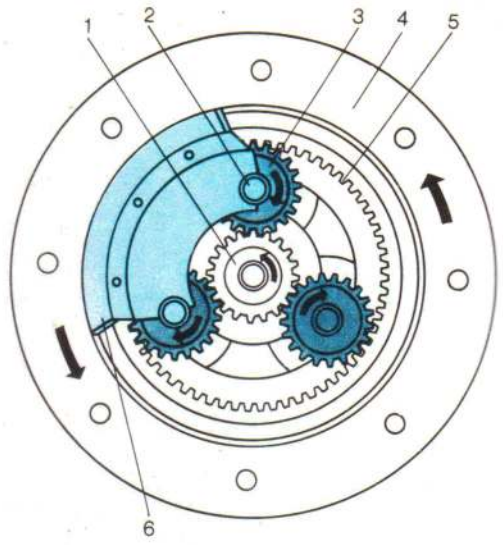
11 installed in the differential carrier. Screwed in the bearing housings from the outside are nuts *12* used to adjust the backlash between the ring gear and drive pinion teeth and the side bearing preload.

Welded to the top of the driving axle housing at both its ends are spring pads. The housings of both driving axles are provided with filler, overflow, and drain holes closed by plugs. Both housings also have vents *3*. The rotating components of the driving axles are lubricated with transmission oil.

As distinct from the automobiles considered in this text, all tractors include final drives in their power trains. The final drives of general-purpose wheeled tractors are referred to as wheel-hub reduction gears.

THE WHEEL-HUB REDUCTION GEARS (Fig. 99), while transmitting power to the driving wheels, increase their torque. These are planetary reduction gear sets consisting of sun gear, or wheel, *2*, three planet, or pinion, gears *4*, planet, or pinion, carrier *5*, stationary internal, or ring, gear *6*, and housing *7*.

The sun gear is splined to the outer end of the axle shaft and is held in place by a nut. The other end of the axle shaft is splined to the differential side gear. The cylindrical planet gears are in constant mesh with both the sun gear and the ring gear and are free to rotate on roller bearings mounted on shafts *3* that are attached to the planet carrier. The planet carrier is fastened to the reduction gear housing by means of studs and nuts. The flange of housing *7*, driving wheel brake drum *13*, and wheel hub *8* are clamped together by bolts. The planet carrier and reduction gear housing form the driven part of the planetary gear set and rotate with the driving wheel of the tractor. The driving gear hub is supported by taper roller bearings mounted on axle shaft housing, or axle sleeve, *11*. The axle sleeve is connected to the stationary ring gear by means of adapter hub *9* that has internal splines and external teeth. The splines are meshed with matching splines on the axle sleeve, and the teeth are meshed with the internal teeth of ring gear *6*.



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Schematic diagram of the planetary reduction gear of Fig. 99

1 – sun gear (wheel);
2 – planet (pinion) gear shaft;
3 – planet (pinion) gear;
4 – reduction gear housing
5 – internal (ring) gear;
6 – planet (pinion) carrier

Referring to Fig. 100, sun gear *1* drives planet gears *3*, causing them to walk around stationary internal ring *5*. Because the planet gear shafts are attached to planet carrier *6*, the rolling planet gears cause the planet carrier to rotate, transmitting the drive to the driving wheel through the reduction gear housing.

The components of the wheel-hub reduction gear are lubricated with transmission oil which is poured in the reduction gear housing through a hole in the center of the housing cover. The filler hole is closed by a plug equipped with a dipstick. The two marks on the dipstick indicate the maximum and minimum permissible oil levels in the reduction gear housing.

12.3. Driving Axles of Row-Crop Tractors

Most row-crop tractors have a *single* driving axle at the rear.

THE REAR AXLE (Fig. 101) includes an axle (main) drive, a differential, two final drives, two brakes, and a differential lock mechanism.

The axle (main) drive comprises a pair of spiral bevel gears. Axle drive bevel pinion *1* is fabricated in the form of a separate gear and is splined directly to the end of the transmission output shaft. Axle drive bevel gear *5* takes the form of a tooth rim and is bolted to split-type differential case *4*. The differential case is supported by two taper roller bearings. Differential side gears *19* are splined on to the inner ends of the final drive pinion shafts. The shafts are made integral with final drive pinions *3* and their outer ends are also splined.

The final drives are arranged on both sides of the rear axle. Each drive comprises a pair of spur gears. The final drive pinion shafts are supported by cylindrical roller bearings installed in carriers *17*. The final drive gears are several times the size of the pinions. The final drive gear hubs are splined to the inner ends of axle shafts *9*.

Attached to the outer ends of the axle shafts are the driving wheels of the tractor. The outer ends of the axle shafts are provided with a series of transverse slots for continuous adjustment of the track width of the tractor. The axle shafts carrying the driving wheels are supported each by two ball bearings, one of which is carried in its respective axle shaft housing, or axle sleeve, *8*. Machined at the inner end of each axle sleeve are a cylindrical locating collar and a flange. The collar fits in a matching bore in the rear axle housing, and the flange is bolted to the housing. Rear fenders are attached to square pads on the top of the axle sleeves. The outer ends of the axle sleeves are closed by covers incorporating lip-type seals to prevent oil leakage from the rear axle housing.

The rear axle components are splash lubricated with oil contained in the rear axle housing. The housing is filled with oil up to the level of an overflow hole.

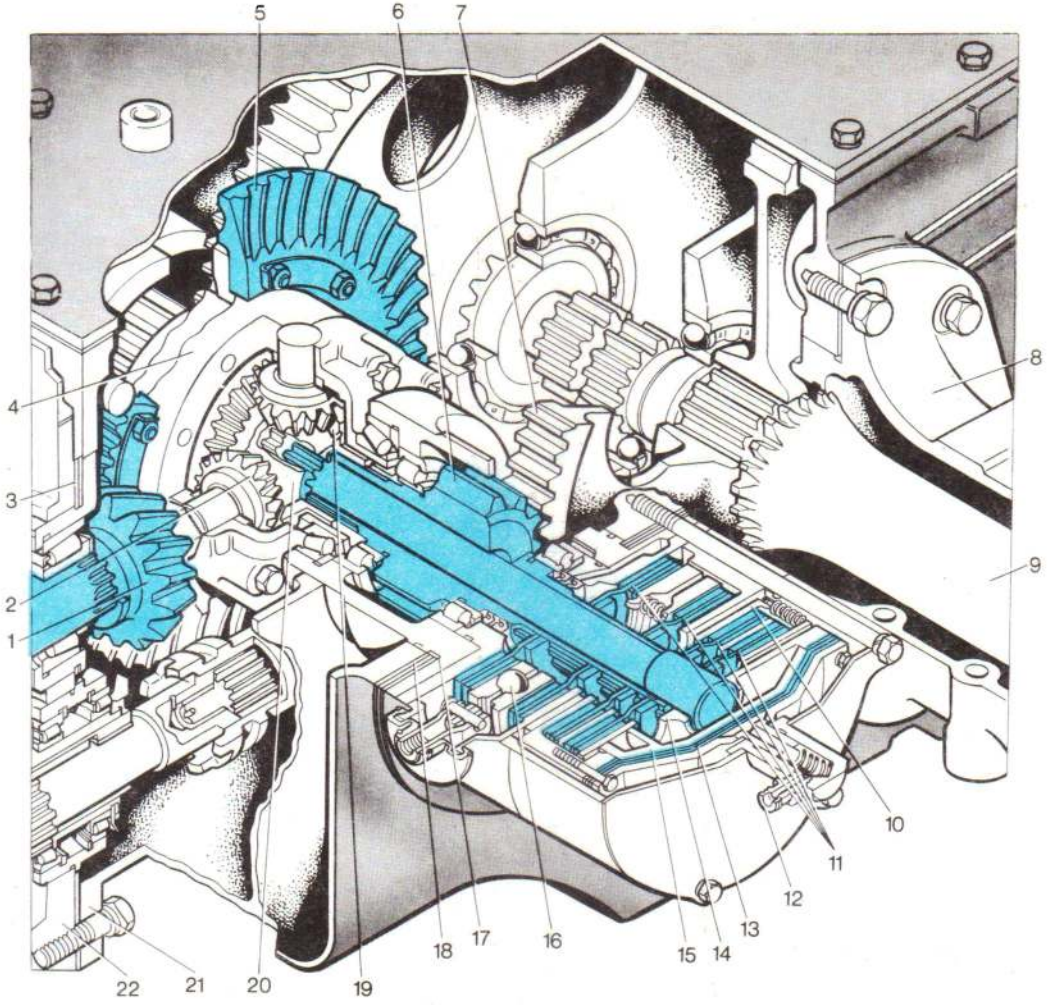
THE DIFFERENTIAL LOCK MECHANISM is necessary to prevent the spinning of one of the *driving rear wheels when the other does not* rotate. The fact that the differential will permit one driving wheel to rotate faster than the other, which is necessary for making turns, is sometimes a disadvantage. For example, if the grip of one of the wheels is insufficient, it will spin around whilst the other wheel will stand still because of the action of the differential.

To lock the differential, it is sufficient to connect rigidly one of the differential side gears to the differential case. The differential lock mechanism used on the tractor considered here operates automatically.

The differential is locked by a hydraulically operated friction clutch whose control circuit is interlocked with the hydraulic servo steering system of the tractor. The automatic differential lock control system consists of a hydraulic actuator attached, together with the differential lock clutch, to the housing of left-hand brake *16* and a sending unit mounted on the body of the hydraulic servo steering control valve.

The differential lock clutch includes a series of driving and driven discs. Driving discs are splined on to the outer end of the left-hand final drive pinion shaft, whereas the driven discs are connected to clutch drum *10*, their external projections fitting in the matching slots in the clutch drum. The clutch drum is rigidly attached to the outer end of differential lock shaft *14* passing through the hollow final drive pinion shaft. The inner end of the differential lock shaft is splined to the differential cross.

With the automatic differential lock control system not in use, the discs of the differential lock clutch are released by spring pressure, so that the differential may operate normally. When the system is operating and the tractor is moving in a straight line, oil under pressure is supplied from the hydraulic servo steering control valve into the space between the cover of the differential lock clutch housing and diaphragm *13*. Oil pressure causes the diaphragm to deflect and move the pressure plate of the differential lock cluch to squeeze the clutch discs which in this position connect in a unit the left-hand final drive pinion shaft, left-



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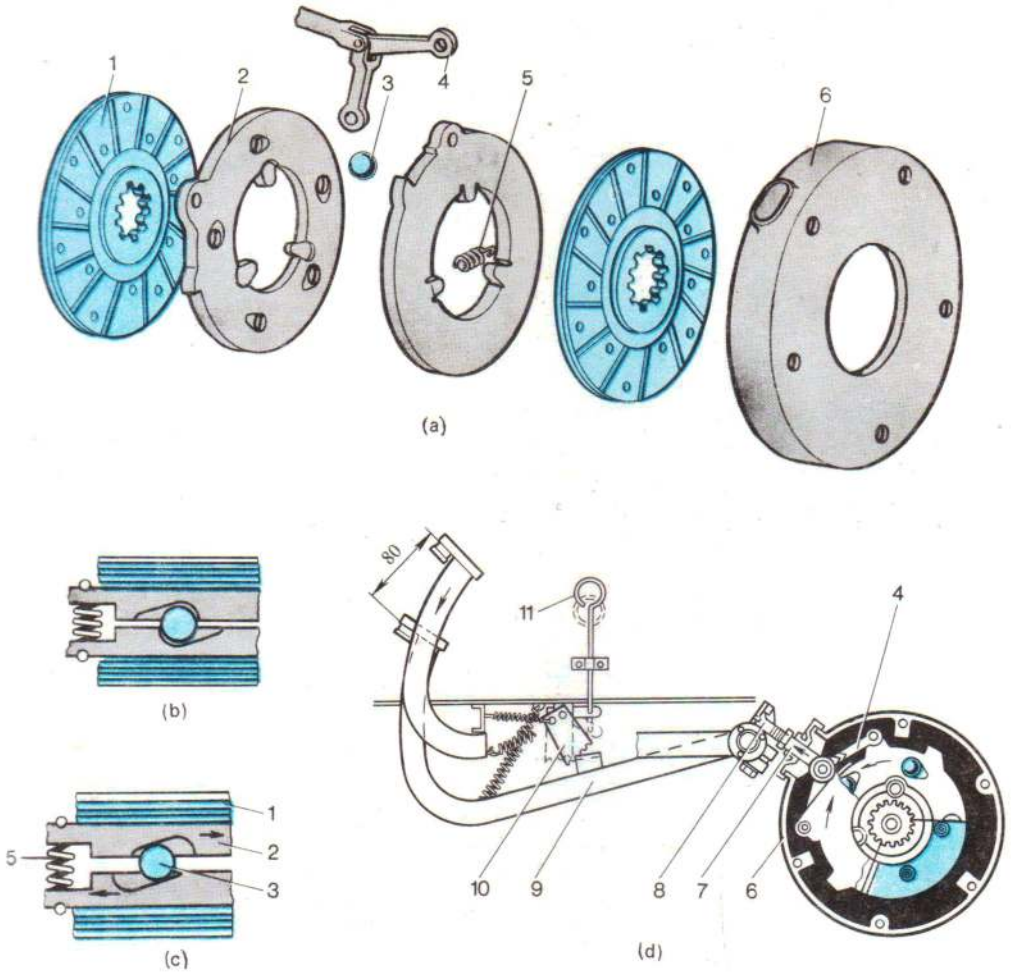
Rear axle of the MT3-80 Model tractor

1 – axle drive bevel pinion;
2 – differential pinion;
3 and 18 – adjusting shims;
4 – differential case;
5 – axle drive bevel gear (differential ring gear);
6 – final drive pinion;
7 – final drive gear;
8 – axle shaft housing (axle sleeve);
9 – axle shaft;
10 – differential lock clutch drum;
11 – friction discs;
12 – oil pipe fitting;
13 – diaphragm;
14 – differential lock shaft;
15 – pressure plate;
16 – left-hand brake;
17 – bearing carrier;
19 – left-hand side gear;
20 – differential cross;
21 – rear axle housing;
22 – transmission case



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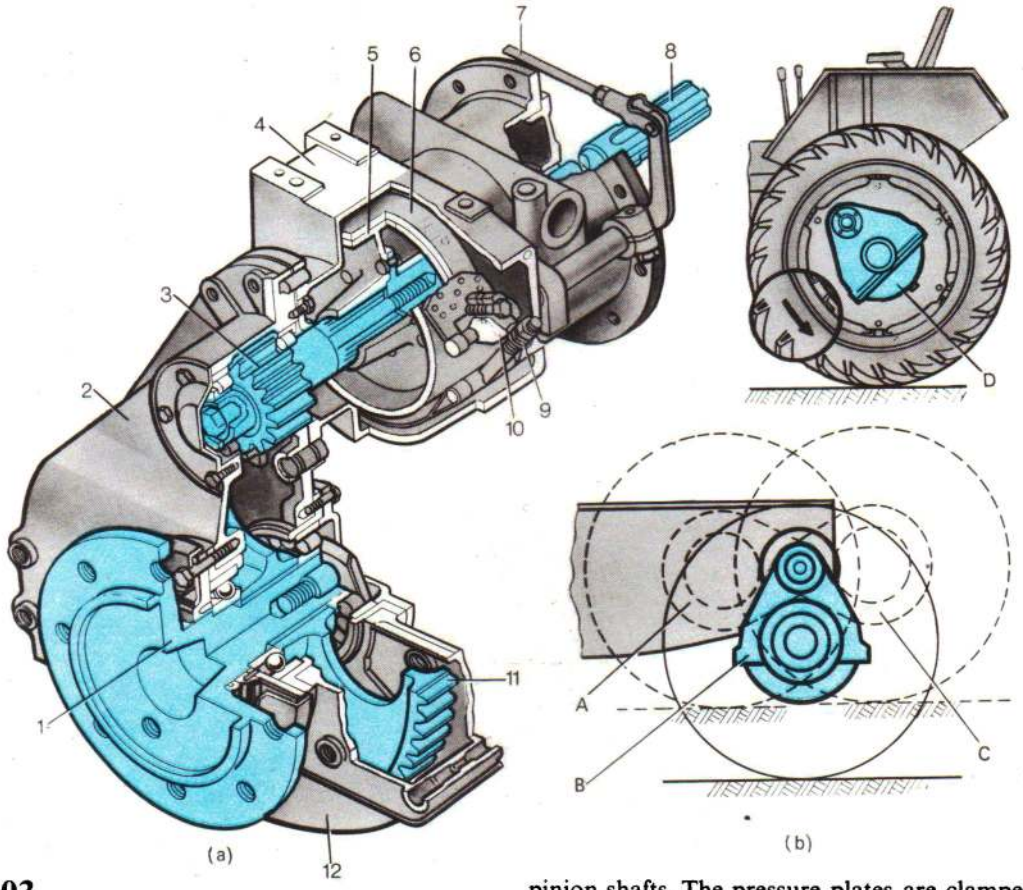
Brake

(a) construction;
(b) brake released;
(c) brake applied;
(d) brake control;
1 – brake disc;
2 – pressure plate;
3 – ball;
4 – brake link;
5 – spring;
6 – housing;
7 – brake rod yoke;
8 – brake rod;
9 – brake pedal;
10 – brake latch;
11 – brake latch rod

hand side gear *19*, differential lock shaft *14*, and differential cross *20*. The differential is thus locked, since the differential pinions cannot move relative to the left-hand side gear.

In some row-crop tractors, the differential can be locked intentionally. In this case, use is made of a foot-operated jaw clutch that rigidly connects together both axle shafts of the tractor.

THE BRAKES (Fig. 102) serve to stop the tractor quickly, if applied simultaneously, and make short turns possible, when applied separately. The brakes are a dry-friction disc type and consists each of housing *6*, two steel brake discs *1*, two cast-iron pressure plates *2*, brake pedal *9*, and brake rod *8* with two brake links *4*. The brake housings are bolted, together with bearing carriers *17* (see Fig. 101) of the



103

Final drive of a row-crop tractor

(a) construction (T-40M Model tractor);
(b) illustrating the clearance adjustment of the T-25A1 Model tractor;
1 – driving wheel shaft;
2 – final drive housing;
3 – final drive pinion;
4 – axle sleeve;
5 – brake pulley;
6 – brake band;
7 – brake rod;
8 – axle shaft;
9 – brake adjusting nut;
10 – brake bell crank;
11 – final drive gear;
12 – oil pan;
A and C – low clearance setting;
B – high clearance setting;
D – basic (medium-height) clearance setting

final drive pinion shafts, to the side walls of the rear axle housing. The brake discs are lined on both sides with a friction material and are splined on to the outer ends of the final drive pinion shafts. The pressure plates are clamped together by three springs *5*. Placed between the pressure plates are five balls *3* that are accommodated in shaped sockets in the inner end faces of the plates.

When the tractor is moving, the brake discs rotate with the final drive pinions. If one of brake pedals *9* is depressed, its associated brake links *4* cause their pressure plates to turn in opposite directions. As the pressure plates turn, the balls clamped between the plates roll over the inclined surfaces of their sockets in the plates, thus causing the latter to move apart and press the rotating brake discs against the stationary surfaces of the brake housing and the bearing carrier flange. This action causes the final drive pinion, hence the associated driving wheel of the tractor, to slow down and then

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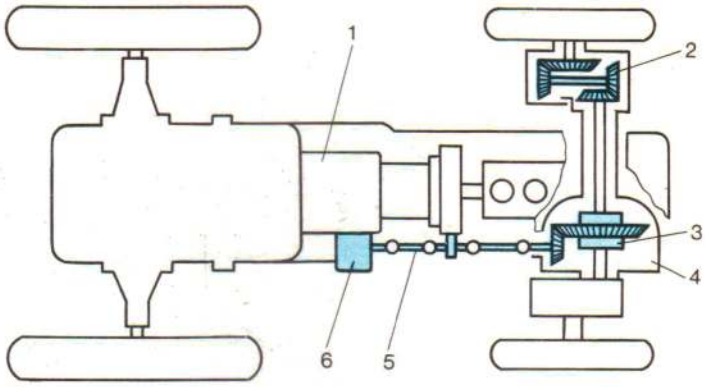
Schematic diagram of a front-wheel drive train

1 – transmission;
2 – final drive;
3 – differential;
4 – front driving axle;
5 – cardan drive;
6 – transfer case



stop rotating completely. Each of the brake pedals can be retained in the applied position by means of latch *10*. Arranged next to the right-hand main brake is a similar brake used as an emergency and/or parking brake. This brake is controlled by a hand lever arranged in the driver's cab.

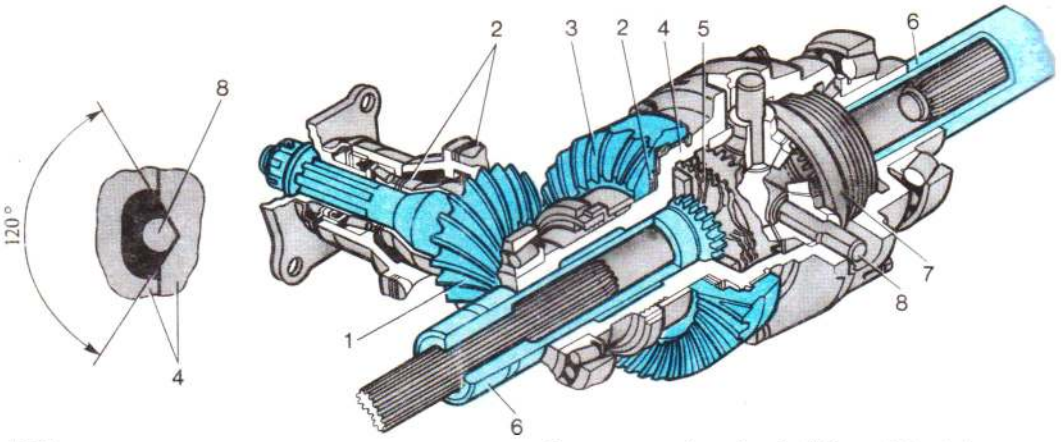
The rear axles of some row-crop tractors share a common housing with the transmission, while their final drives are enclosed in separate cast housings *2* (Fig. 103*a*). Placed between each final drive housing and the rear axle housing is axle sleeve *4*. The final drive housings are bolted to their respective axle sleeves, dowels being used to locate the housings in a definite position with respect to the axle sleeve flanges. Final drive gears *11* are splined to shafts *1* made integral with the driving wheel flanges. Final drive pinions *3* are splined to the outer ends of axle shafts *8*. Splined on to each axle shaft is brake pulley *5* encircled by steel brake band *6* with a riveted-on friction lining. The ends of the brake band are linked with bell crank *10* which in turn is linked with a brake pedal by means of rod *7*. When the pedal is depressed, the ends of the brake band are drawn together, so that the band is tightly pressed against the brake pulley to brake it together with its associated axle shaft and driving wheel.

The final drive housings can be located in various positions relative to the axle sleeves, which makes it possible to change in a stepwise fashion the wheel base and clearance of the tractor. The following three clearance settings are possible (Fig. 103*b*): basic (medium-height), high, and low. The tractor can be made to have low clearance setting by turning the final drive housings either fully backward or fully forward, provided the driver's cab is removed and the track width of the rear wheels is set at its minimum. In this case, one should bear in mind that turning the final drive housings forward improves the manoeuvreability of the tractor but impairs its stability, and vice versa turning them backward improves the stability of the tractor but impairs its manoeuvreability.

FRONT DRIVING AXLE. Some row-crop tractors are of four-wheel drive type, i.e., they are equipped with a front driving axle (Fig. 104). Since all the four wheels of such a tractor are driving, the whole of the tractor's weight is utilized for traction, and so the tractor possesses improved traction characteristics and cross-country capability. The front-wheel drive train includes transfer case *6* and cardan drive *5* described in Chapter 11.

The front driving axle (Fig. 105) of a row-crop tractor consists of an axle drive, a differential, and final drives. The principal structural components of the front driving axle are a housing and a cover that are bolted together to form a rigid, hollow beam. The beam is pivoted to the front cross member of the tractor frame.

THE AXLE (MAIN) DRIVE comprises a pair of spiral bevel gears. Axle drive pinion *1* is made integral with its shaft that is supported by two taper roller bearings held in a carrier. The bearing carrier is attached to the axle housing,



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Front driving axle of the MT3-82 Model tractor

1 – axle drive pinion;
2 – adjusting shims;
3 – axle drive gear (differential ring gear);
4 – differential case;
5 – friction-type differential lock clutch;
6 – differential side gear;
7 – pressure cup;
8 – differential pinion shaft

shims *2* being used between the bearing carrier flange and the axle housing to adjust the position of the axle drive pinion relative to the axis of the axle.

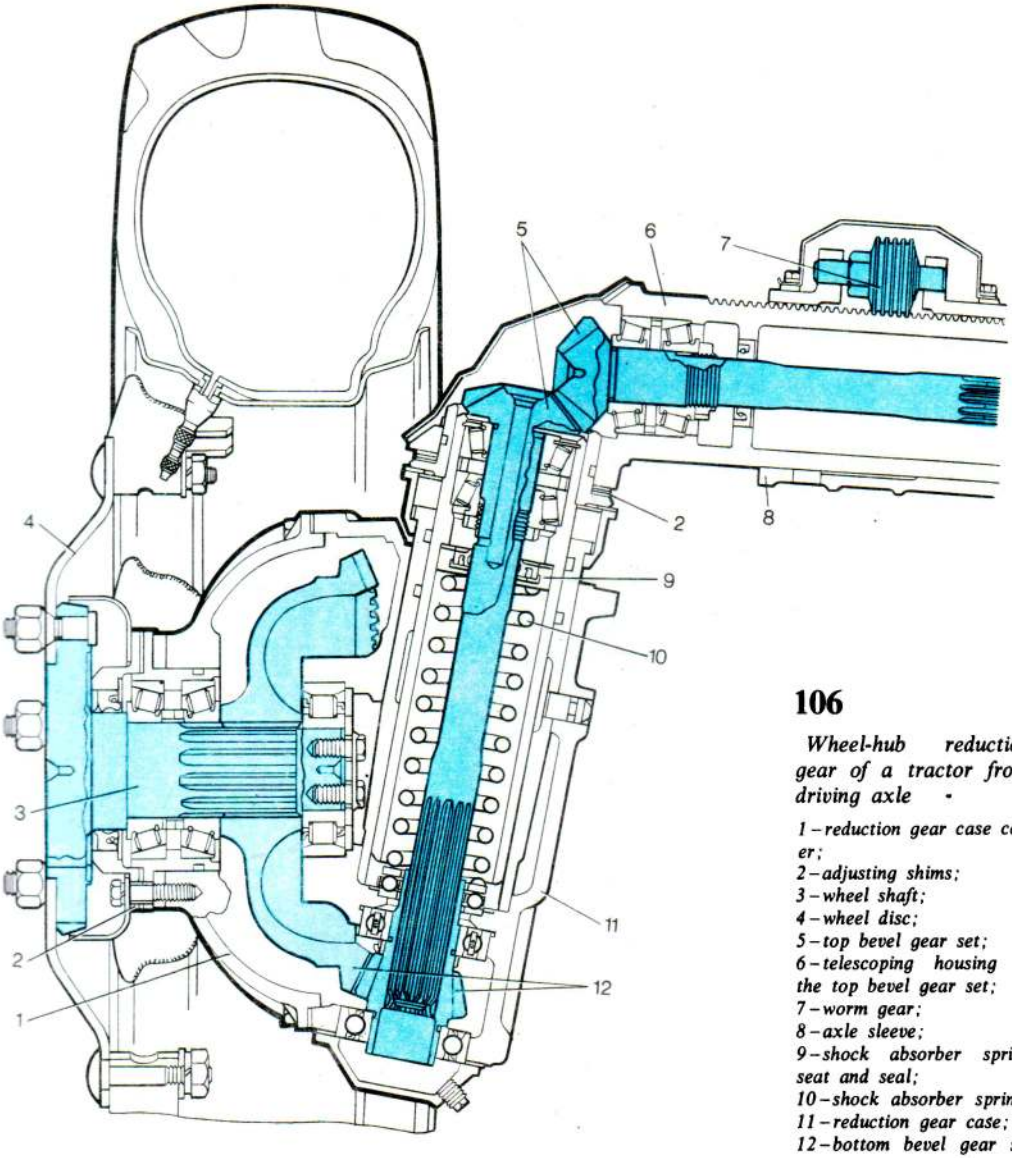
Axle drive gear *3* is splined on to differential case *4* and is clamped between a spacer sleeve and a thrust collar on the differential case by a special nut. To adjust the backlash between the axle drive pinion and gear teeth, use is made of adjusting shims placed between the thrust collar and the axle drive gear.

THE DIFFERENTIAL is a self-locking (or nonslip) bevel gear type with a floating cross. The differential case is of split construction and is supported by two taper roller bearings carried in the split front axle housing. The four differential pinions are carried in pairs on two shafts *8* arranged at right angles. With the front driving axle engaged, the differential pinion shafts may be displaced in opposite directions, since they lie rather loosely in notches in the two halves of the differential case. Placed between each pair of differential pinions and the differential case are pressure cups *7* that are splined to differential side gears *6*. The spaces between the cups and the differential case house friction-type differential lock clutches *5*, each comprising a set of driving and driven discs made of steel. The driving discs are splined to the differential case and the driven ones, to the differential side gears.

The rotating differential case carries the differential pinion shafts around with it. Since there is considerable side thrust, the differential pinion shafts tend to slide up the sides of the notches in the two halves of the differential case. As the differential pinion shafts slide up, they are forced outward. This force is carried through the pressure cups to the two sets of clutch discs. The clutch discs lock the axle shafts to the differential case. Therefore both wheels turn.

If one of the front wheels starts slipping while driving in a straight line, the differential pinions begin rotating on their shafts. This causes the shafts to change position in their notches in the differential case, so that the pressure applied by the cylindrical surfaces of the differential pinions to the pressure cups to compress the friction discs of the differential lock clutches will increase for the lagging axle shaft and decrease proportionately for the leading axle shaft. In this way, the front driving wheels are prevented from slipping individually.

During normal driving, if the tractor rounds



106

Wheel-hub reduction gear of a tractor front driving axle

1 – reduction gear case cover;
2 – adjusting shims;
3 – wheel shaft;
4 – wheel disc;
5 – top bevel gear set;
6 – telescoping housing of the top bevel gear set;
7 – worm gear;
8 – axle sleeve;
9 – shock absorber spring seat and seal;
10 – shock absorber spring;
11 – reduction gear case;
12 – bottom bevel gear set

a curve, pressure is released on the clutch for the inner wheel just enough to permit some slipping. This release of pressure permits the outer wheel to turn faster than the inner wheel.

The higher the resistance applied to the front driving wheels, the higher the degree of compression of the differential lock clutch discs, hence the degree of locking of the differential. If there is no slipping of the rear wheels of the tractor, the front driving axle is automatically disengaged. With no driving torque applied to the differential, no pressure is applied to the friction discs of the differential lock clutches.

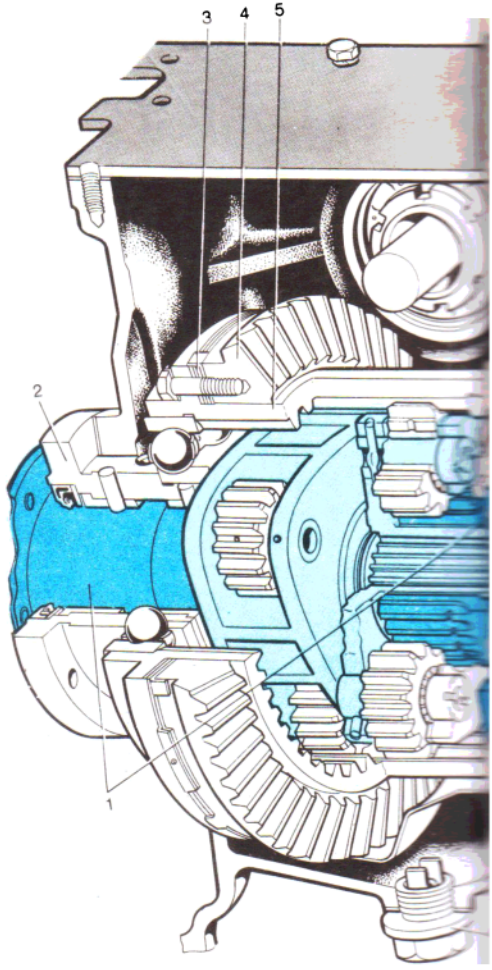
THE FINAL DRIVE takes the form of a wheel-

hub reduction gear (Fig. 106) consisting of two pairs of bevel gears: top bevel gear set *5* and bottom bevel gear set *12*. Housings *6* of the top bevel gear sets of both final drives are inserted in a telescopic manner into axle sleeves *8* of the front axle housing, which makes it possible to change the track width of the front wheels.

Continuous adjustment of the track width of the front wheels is effected by means of worm gear *7* consisting of a worm held to the axle sleeve and a rack on the top bevel gear set housing. Before making the adjustment, it is necessary to jack up the front axle to clear both wheels of the ground and remove the taper bolts that lock telescoping housings *6* in position.

The driven gear of the bottom bevel gear set is supported by two taper roller bearings in the cover of reduction gear case *11* and a cylindrical roller bearing in the case. The hub of the driven gear is splined to the end of wheel shaft *3* with wheel disc *4* attached to its flange. The driving gear of the bottom bevel gear set is supported by two ball bearings and is splined on to the bottom end of the vertical shaft of the reduction gear. The sliding connection between the driving gear and the vertical shaft makes it possible to spring the wheel.

The rubbing components of the front driving axle are lubricated with oil which is poured in the front axle housing, top bevel gear set housing, and reduction gear case. Leakage of oil from the housings and the case is prevented by means of lip-type seals and rubber sealing rings.

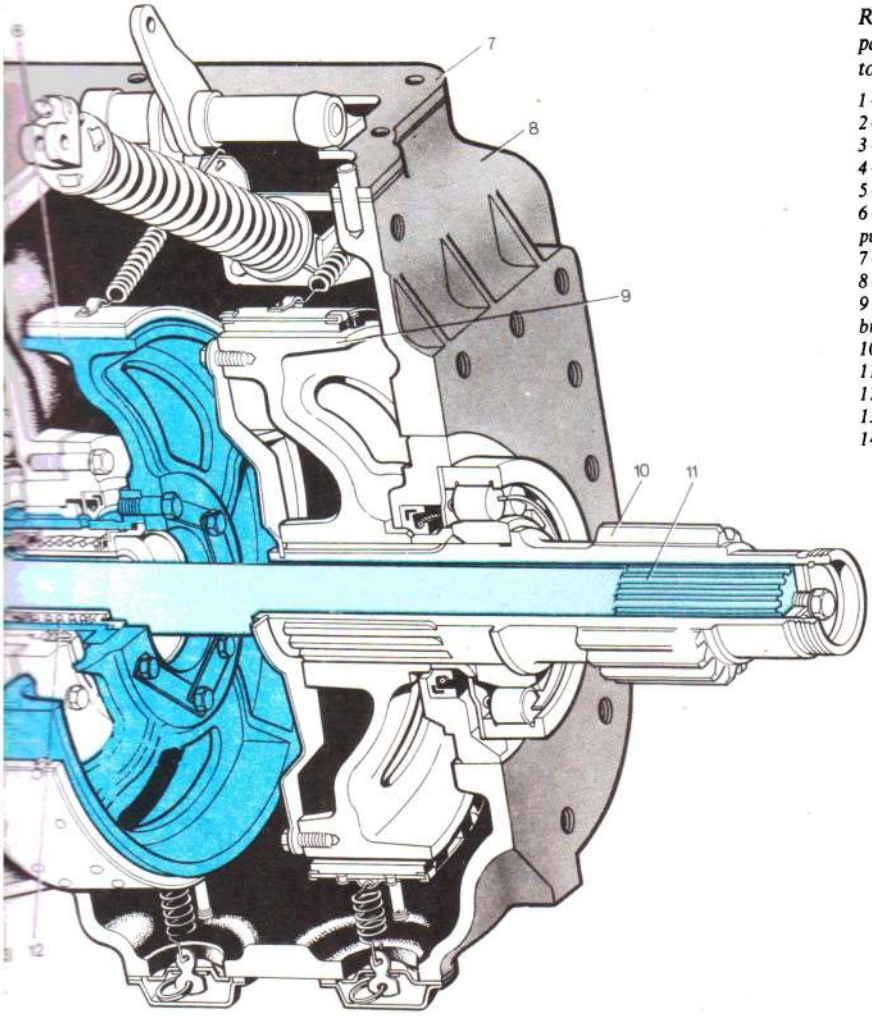


12.4. Rear Axle of Crawler Tractor

The rear axle (Fig. 107) of a crawler tractor includes an axle (main) drive, planetary steering mechanisms, and final drives.

The mechanisms of the rear axle are accommodated in a housing at the rear of the transmission case, which is partitioned into three compartments. The central compartment houses the axle drive and planetary gear sets of the steering mechanisms, and the other two compartments accommodate sun gear (steering) and axle shaft (stopping) brakes. The final drives are carried in separate housings.

THE AXLE (MAIN) DRIVE includes a pair of bevel gears. The axle drive pinion (not shown in the figure) is made integral with the transmission output shaft. Axle drive gear *4* is



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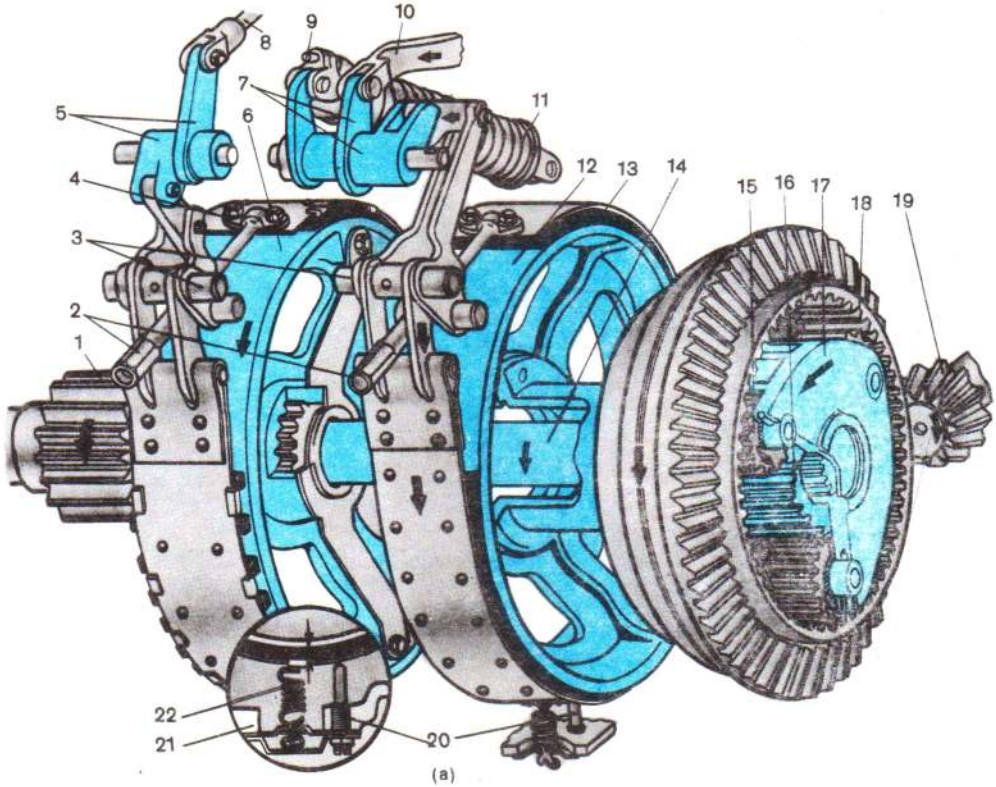
Rear axle (right-hand part) of a crawler tractor

1 – sun gears;
2 – bearing carrier;
3 – adjusting shims;
4 – axle drive gear;
5 – internal gear;
6 – sun gear (steering) brake pulley;
7 – cover;
8 – housing;
9 – axle shaft (stopping) brake pulley;
10 – final drive pinion;
11 – axle shaft;
12 – seal;
13 – oil baffle;
14 – drain plug

fabricated in the form of a tooth rim and is bolted to the flange of internal gear *5*, steel shims *3* being used between the axle drive gear and the internal gear flange to adjust the backlash between the axle drive pinion and gear teeth. To facilitate their installation and removal, the shims are made in the form of half-rings with slots opening inward for the fastening bolts.

The internal gear is supported by two ball bearings whose outer races are press-fitted into bores made in the bores machined in the gear.



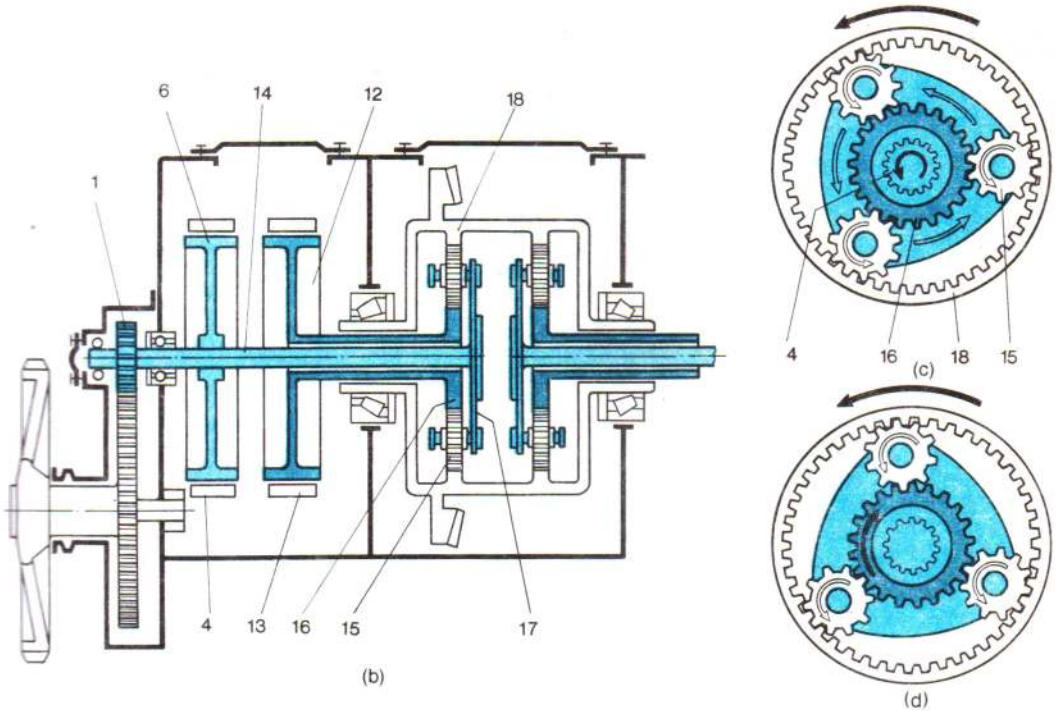
The inner races of the bearings are mounted on carriers whose flanges are bolted to the partitions inside the rear axle housing.

THE PLANETARY STEERING MECHANISM (Fig. 108*a*) consists of a planetary gear set and two brakes – the sun gear, or steering, brake and the axle shaft, or stopping, brake. The mechanism serves to slow down or stop completely its associated track, thus causing the tractor to make a turn. The planetary gear set is arranged inside the internal gear which forms part of the set. The set also includes planet carrier *17*, three planet gears *15*, and sun gear *16*.

The planet carrier is cast in steel in the form of two triangular flanges interconnected by webs. In the center of the planet carrier is a cast-on hub with internal splines that mesh with matching splines on the inner end of axle shaft *14*. The outer end of the axle shaft is also provided with splines that mesh with internal splines of final drive pinion *1*. Splined on to the inner end of the pinion shaft that projects inside the brake compartment of the rear axle housing is stopping brake pulley *6*.

The planet gears are freely supported on their shafts in the planet carrier by needle bearings and are in constant mesh with both internal gear *18* and sun gear *16*. The sun gear is made in the form of a cylinder with teeth at one end and a flange with threaded holes at the other. Bolted to the sun gear flange is sun gear brake pulley *12*.

Both brake pulleys are encircled by brake bands. Each brake band is cut in half and then the halves are hinged together. Such a construction of the bands enables them to be replaced without dismantling the brake pulleys.



108

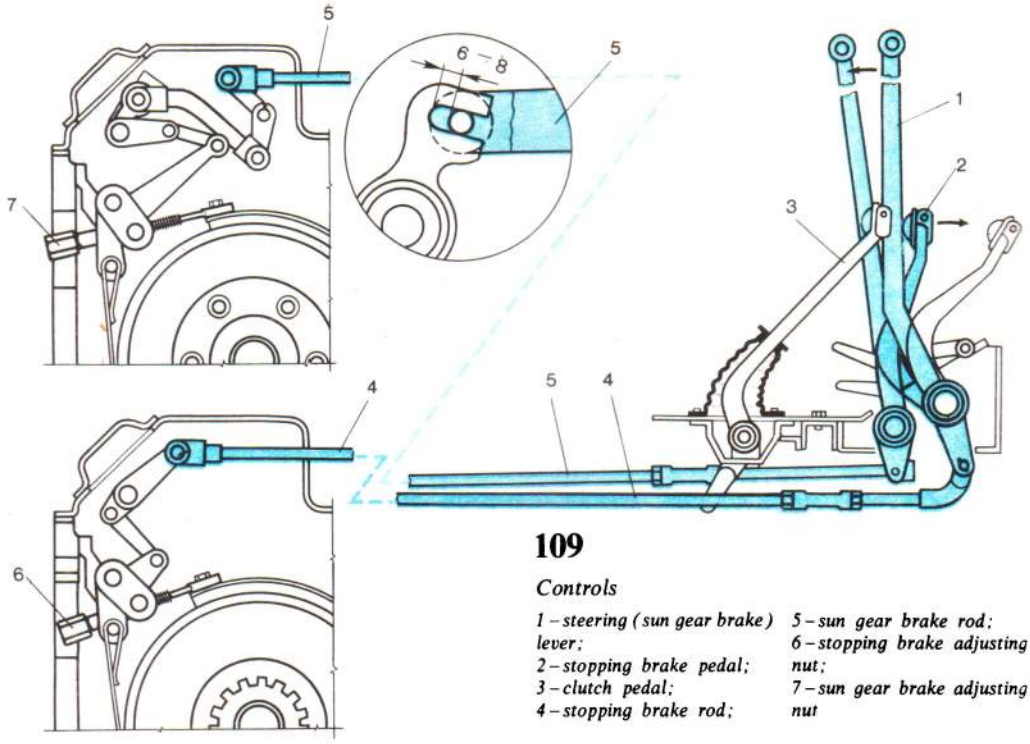
Planetary steering mechanism (left-hand)

a) construction;
b) schematic diagram;
c) illustrating the interaction of gears when the tractor is moving in a straight line;
d) illustrating the interaction of gears when the tractor rounds a turn;
1 – final drive pinion;
2 – adjusting nuts;
3 – pins;
4 – stopping brake band;
5 – stopping brake bell crank;
6 – stopping brake pulley;
7 – sun gear (steering) brake bell crank;
8 – stopping brake rod;
9 – sun gear brake adjustment indicator rod;
10 – sun gear brake rod;
11 and 22 – springs;
12 – sun gear brake pulley;
13 – sun gear brake band;
14 – axle shaft;
15 – planet gear;
16 – sun gear;
17 – planet carrier;
18 – internal gear;
19 – axle drive pinion;
20 – adjusting screws;
21 – rear axle housing

The planetary steering mechanisms operate as follows (Fig. 108*b*). When the tractor runs in a straight line, both sun gears are held stationary, their brakes being fully applied, while the axle shafts are free to rotate.

The axle drive transmits rotation to internal gear *18* which drives planet gears *15*. While turning on their shafts, the planet gears must walk around the stationary sun gears *16* (Fig. 108*c*), since they are meshed with them. As the planet gears walk around the sun gears, they carry their carriers around with them. The carriers turn their associated axle shafts and final drive pinions. In this case, the rotational speed of the planet carriers, as compared to that of the internal gear, is reduced by a factor of 1.4, while their torque is increased proportionately.

To turn the tractor smoothly to the right or left, the driver has to pull back on the corresponding sun gear brake (steering) lever. This will compress the clamping spring of the sun gear brake band, releasing the sun gear brake pulley, the sun gear will be freely driven by the planet gears (Fig. 108*d*), and the track on



109

Controls

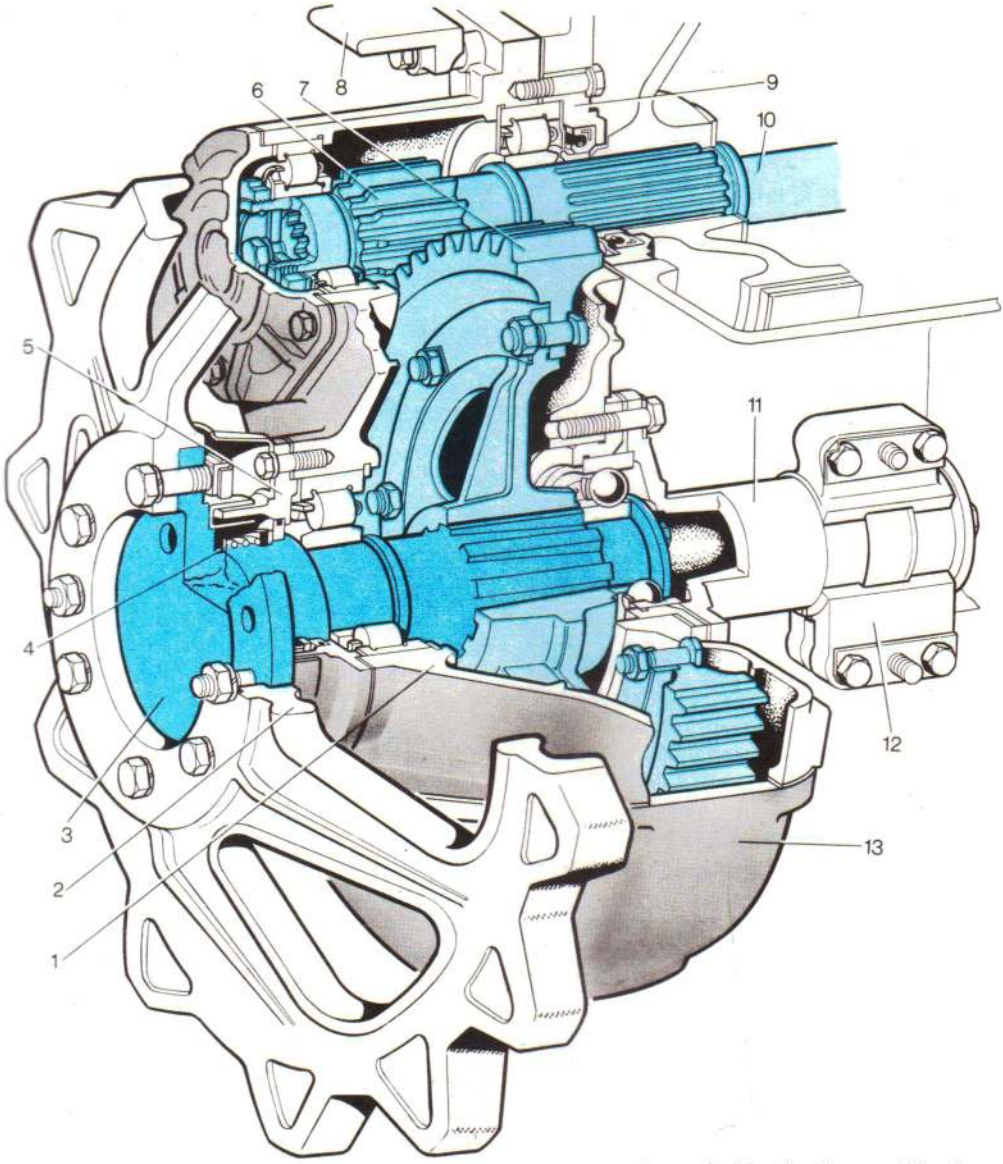
1 – steering (sun gear brake) lever;
2 – stopping brake pedal;
3 – clutch pedal;
4 – stopping brake rod;
5 – sun gear brake rod;
6 – stopping brake adjusting nut;
7 – sun gear brake adjusting nut

the side of the released sun gear will slow down. The tractor will smoothly turn in the direction of the lagging track. To make a sharp turn, the driver, after pulling back on the steering lever, should step on the stopping brake pedal on the same side. This will brake the corresponding stopping brake pulley *6*, and the track will stop completely. The tractor will then turn sharply in the direction of the stopped track.

All the brake bands are made of steel. Riveted on the inner surface of the sun gear brake bands are solid friction linings, whereas the stopping brake bands are provided each with a set of riveted-on blocks of hard friction material. In a free state, each brake band has the shape of a circle, and there is a clearance of 1.5 to 1.8 mm between the bands and the brake pulleys. For the clearance to be uniform, use is made of release springs *22* and adjusting screws *20* that are screwed in the threaded holes in the rear axle housing.

The upper ends of the brake bands are connected to adjusting screws carrying adjusting nuts *2*. Riveted to the other ends of the bands are strip-steel eyes. The eyes are provided with slots that receive the links connecting the pins in the eyes with pins *3* which are carried on the levers pivoted to the brackets (not shown in the figure) fixed to the rear wall of the rear axle housing. Pins *3* are linked with brake bell cranks *5* or *7*. Stopping brake bell crank *5* is linked by rod *8* with its associated brake pedal. and sun gear bell crank *7* is linked by rod *10* with the corresponding steering lever. One of the arms of bell crank *7* is acted upon by strong spring *11* which tends to turn the bell crank clockwise (as viewed from the right) to press tightly, and with a great force, the sun gear brake band against its pulley *12*.

The gears of the planetary steering mechanisms are lubricated with oil poured in the central compartment of the rear axle housing. To prevent the oil from leaking into the brake compartments, use is made of sealing



110

Final drive

1 – housing;
2 – track drive sprocket;
3 – track sprocket shaft;
4 – sealing arrangement;
5 and 9 – seal carriers;
6 – final drive pinion;
7 – final drive gear rim;
8 – guard;
10 – axle shaft;
11 – support;
12 – yoke;
13 – housing cover

arrangements carried in the bores of both sun gears and rear axle housing partitions. The oil leaking past the seals is drained from the brake compartments through threaded holes in the bottom of the rear axle housing that are closed by plugs.

The controls of a crawler tractor include steering levers and brake pedals that are

arranged in the driver's cab and linked with their associated brake mechanisms in the rear axle housing by a system of rods and levers.

Figure 109 shows schematically levers *1* and pedals *2* of the left- and right-hand steering (sun gear) and stopping brakes. Lever *1* operates the band of the sun gear brake through the medium of rod *5*, and pedal *2* operates the band of the stopping brake through the intermediary of rod *4*. The normal free play of the steering levers is 80 to 100 mm, which corresponds to a clearance of 6 to 8 mm between the pin at the end of rod *5* and the mating arm of the sun gear brake bell crank. This clearance is adjusted by means of nut *7*. The clearance between the band and pulley of the stopping brake is adjusted by means of nut *6*. With this clearance adjusted properly, the stopping brake is fully applied when its pedal is depressed just enough for it to be latched in the first notch of the brake pedal quadrant.

For convenience, the steering levers are provided with plastic grips, and the brake pedals, with pads. The levers and pedals are supported by cermet bushings on shafts that tightly fit in holes in cast-iron brackets held to the tractor frame. The bushings are lubricated through lubrication fittings screwed in the end faces of the shafts.

THE FINAL DRIVES (Fig. 110) transmit rotation from the axle shafts to the track drive sprockets.

The tractor uses two final drives arranged on both sides of the rear axle housing. Each final drive consists of a pair of spur gears enclosed in cast-iron housing *1*.

Final drive pinion *6* is supported by two roller bearings installed in bores in the housing. The pinion is splined on to the end of axle shaft *10*.

The final drive gear is of built-up construction. Its rim *7* of high-quality steel is fastened by dowel bolts to the hub that is tightly fitted on the taper splines of track sprocket shaft *3*. The shaft is supported by a roller and a ball bearing carried in the bores of the housing. Track drive sprocket *2* is fixed by six bolts to the flange of the shaft. Leakage of oil from the final drive housing is prevented by sealing arrangement *4*. The housing is bolted to the side wall of the rear axle housing. Support *11* of the final drive housing is also attached to the rear axle housing by means of yoke *12*. When assembled to the rear axle housing and mounted on the tractor frame, the final drive housings rest with the central necks of their supports *11* in sockets provided in the rear brackets of the frame, where they are rigidly held in place. In this way, the thrust developed by the track drive sprockets during operation is transmitted to the frame of the tractor.

Steel guard *8* mounted at the top part of the final drive housing serves to protect the housing against its being worn through by the moving track.

The final drive housing, which is made open from below to allow installing the final drive gear, is closed by steel cover *13*. The cover is provided with oil overflow and drain holes that are closed by plugs. The final drive housing is filled with oil through a filler neck at the top of the housing. The filler neck is closed by a vented cap.

12.5. Driving Axle Troubles

Most common driving axle troubles include oil leaks, improper operation of the brakes, excessive wear of components causing increased noise and overheating of the driving axle mechanisms, and breakage of components. Oil leaks can be clearly seen on clean surfaces of structural parts, therefore the tractor or automobile should be daily cleaned from dirt on the outside. Oil leaks may be caused by worn seals or damaged or loose sealing gaskets, or else by loose joints between individual structural components of the driving axle. The trouble is corrected by tightening up loose fasteners or by replacing worn seals or damaged sealing gaskets.

Worn sealing arrangements on a tractor may result in oil getting onto the friction linings of the brakes, thus causing the brakes to fail. Contaminated friction linings are usually washed immediately after the tractor has been stopped, while the linings are still hot and it is easier to wash oil from them. The linings are

washed with tractor fuel and a special gun, the brakes being held fully released. After the linings have been washed, the fuel is drained from the brake compartments of the driving axle housing, and the brakes are held released until the linings are completely dry.

The bevel gears of the axle drive will operate normally if the apices of the generating cones of both the pinion and the gear coincide with the point of intersection of theit axes. No degree of the gear machining precision can alone ensure meeting this condition. Therefore, during assembly, the pinions and gears are matched and adjusted, and so they should be replaced, if excessively worn, only as a set. Incorrect internal adjustment of the axle drive pinion and gear often causes a humming noise which takes on a growling sound as tooth wear progresses.

Various noises may be caused by dry, worn, or broken gear teeth or bearings. If the noise is present only when the tractor or automobile is going around a curve, the trouble is in the differential case. Differential pinions tight on the differential cross or pinion shafts, damaged differential side gears or pinions, too much backlash between gears, or worn differential case bearings can cause this trouble. Incorrectly adjusted or damaged taper roller bearings will cause overheating of their housings. If oil is lacking, it should be replenished. Excessively worn or damaged components should be replaced, and adjustment of gears or bearings should be corrected, if necessary.

Premature wear and failure of the driving axle components may be caused by the use of improper lubricant. This is especially true of automobile driving axles employing hypoid gears.

Certain rules should be observed to prevent damage to the components of the rear axle mechanisms. When driving a tractor around tight curves, depress the brake pedals smoothly. Do not turn the tractor sharply while it is running at a high speed.

If your wheeled tractor is equipped with a differential lock that can be engaged intentionally, use the lock only when one of the rear wheels is slipping badly. Do not turn the tractor with the differential locked.

Review Questions

1. What are the mechanisms the driving axle consists of?
2. What types of axle (main) drives do you know?
3. How does the wheel-hub reduction gear of a general-purpose tractor operate?
4. What is the purpose of the differential?
5. What is the purpose of the automatic differential lock mechanism?
6. What is the difference between the front and rear differentials of a row-crop tractor?
7. How can the final drives be used to change the wheel base and clearance of a row-crop tractor?
8. Explain the operation of the planetary steering mechanism of a crawler tractor.
9. List the most common driving axle troubles.
10. What are the rules to be observed to prevent damage to the rear axle mechanisms?

Chapter 13
Running Gear

13.1. Frame and Suspension of Automobiles and Wheeled Tractors

The running gear (Fig. 111) transforms the torque applied to the driving wheels into the translatory motion of the tractor or automobile. It includes an undercarriage, a suspension, and a propeller (wheels or tracks).

The undercarriage is a frame or some other structure that supports the engine and cab (body) of the tractor or automobile and is in turn supported by the wheels or tracks.

The undercarriage of wheeled tractors may be of framed, semi-framed, or frameless type.

The framed undercarriage is essentially a riveted or welded frame of various steel sections.

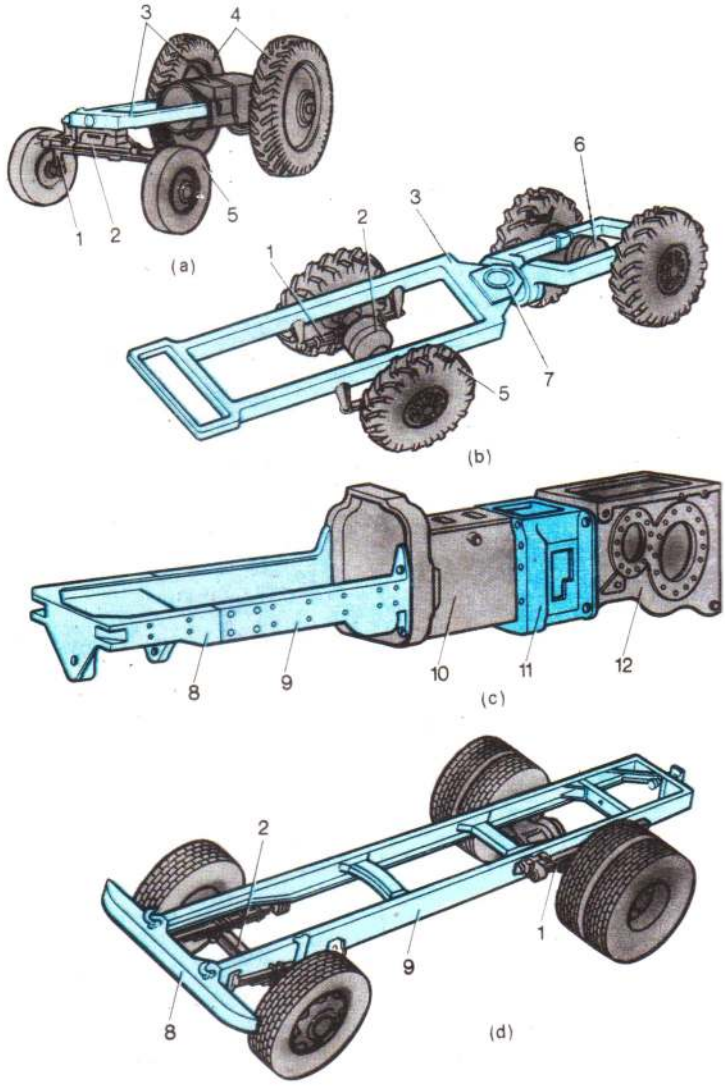
The semi-framed undercarriage (Fig. 111*c*) is a composite structure formed by the structural members of the power train units that are rigidly held together and a half-frame attached to the assembly.

111

(a), (b), and (d) Running gear (chassis) and (c) undercarriage

(a) and (c) of a row-crop tractor;

(b) of a general-purpose tractor;
(d) of an automobile;
1 – suspension;
2 – front axle;
3 – undercarriage;
4 and 5 – rear and front wheels;
6 – rear axle;
7 – double-hinged joint;
8 – front cross member;
9 – side member (girder);
10 – clutch case;
11 – transmission case;
12 – rear axle housing

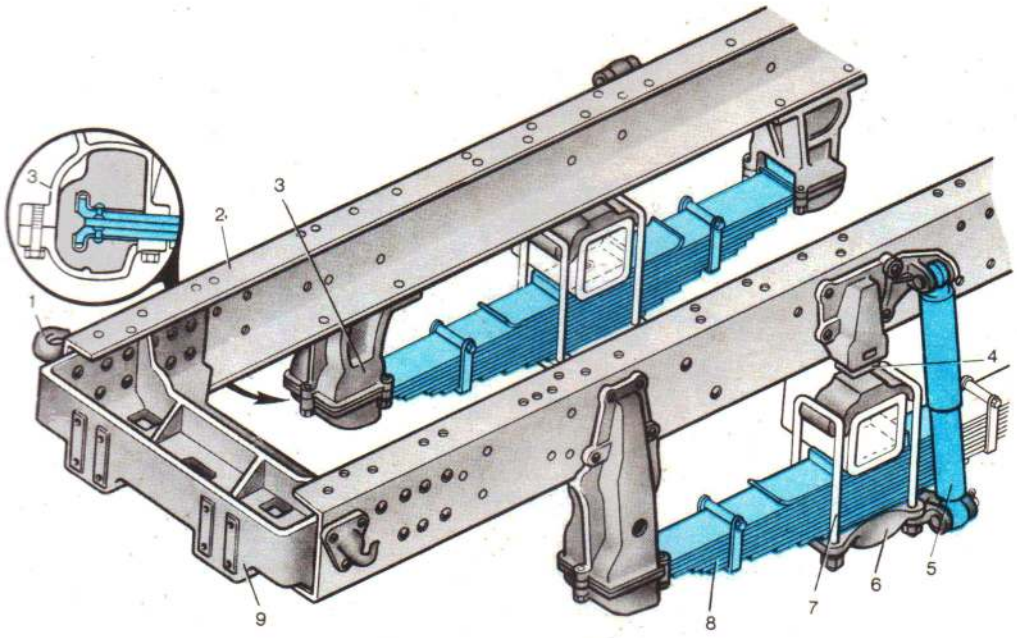


The frameless undercarriage is a rigid structure that is wholly formed by the structural members of the engine and the power train units.

The semi-framed and frameless types of undercarriage find application in row-crop tractors.

THE FRAME OF AN AUTOMOBILE (Fig. 111*d*) is made up of two channel-section side members (girders) and several cross members that are held together by rivets. The frame is provided with welded-on gusset plates and angle pieces for rigidity and brackets for mounting the various units of the automobile.

THE FRAME OF A GENERAL-PURPOSE WHEELED TRACTOR (Fig. 111*b*) is articulated. It consists of two halves (half-frames) that are connected together by a double-hinged joint



112

Front suspension of the T-150K Model tractor

1 – tow hook;
2 – side member (girder);
3 – spring bracket (hanger);
4 – rubber spring bumper stop);
5 – hydraulic shock absorber;
6 – spring clamp (clip) plate;
7 – spring clip (U-bolt);
8 – leaf spring;
9 – front cross member

allowing the half-frames to turn relative to each other in both horizontal plane (within $\pm 30°$) and vertical plane (within $\pm 18°$). Such a frame construction enables the tractor to be turned without using any steerable wheels. The body of the double-hinged joint is provided with levers that are connected to the hydraulic cylinders of the steering system, called the articulated frame steering system. In some instances (e.g., when lifting the tractor with slings), the hinge is locked by means of a bolt and nut.

THE SUSPENSION is a system of devices that effect an elastic connection between the undercarriage and the wheels or tracks. Its purpose is to absorb any road (field) shocks that result from the wheels or tracks hitting holes or bumps.

General-purpose wheeled tractors use only a front suspension (Fig. 112). The front axle of the tractor is suspended from its front half-frame by two semielliptic springs. The springs are held rigidly to the axle, by spring clamp (or clip) plates *6* and spring clips (or U-bolts) *7* and elastically to the half-frame, through rubber blocks in their brackets (or hangers) *3*. Rubber bumpers *4* on the half-frame above the axle serve to absorb the shock that would result if the axle actually moved up far enough to hit the half-frame. The downward travel of the front axle is limited by the shackles of the spring lock mechanism that is used to lock the springs when the tractor is equipped with a bulldozer blade or some other front-mounted implements.

Shock absorbers *5* installed between the half-frame and the springs serve the purpose of damping oscillations of the springs.

Trucks use a similar front suspension but have no spring lock mechanism. On trucks, the front axle (Fig. 113*a*) is made in the form of an

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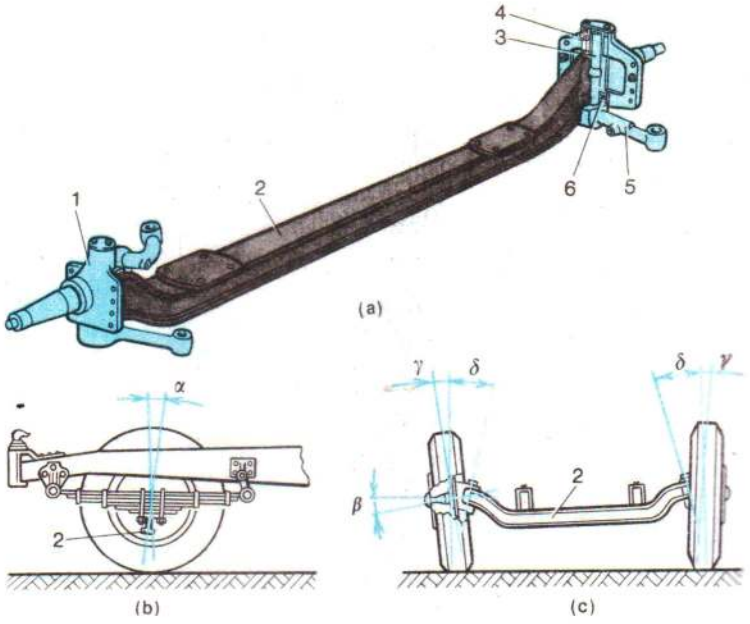
Front axle of an automobile

(a) construction;
(b) illustrating wheel caster;
(c) illustrating kingpin (steering-axis) inclination;
1 – steering knuckle;
2 – I-beam axle;
3 – kingpin (steering knuckle pivot);
4 – lubricator;
5 – steering knuckle arm (lever);
6 – kingpin thrust bearing;
α – caster angle;
β – spindle tilt;
γ – camber angle;
δ – kingpin (steering-axis) inclination (kingpin angle)



I-beam whose ends are bent upward. The axle is provided with special pads for fastening the springs. Carried on the ends of the axle beam are bosses, called king posts, with eyes that receive kingpins *3*, or steering knuckle pivots, connecting steering knuckles *1* of the front steerable wheels with the axle. To ease turning the steering knuckles, use is made of kingpin, or steering knuckle, thrust bearings *6*. The wheel hubs are mounted each on two taper roller bearings on the steering knuckle spindles.

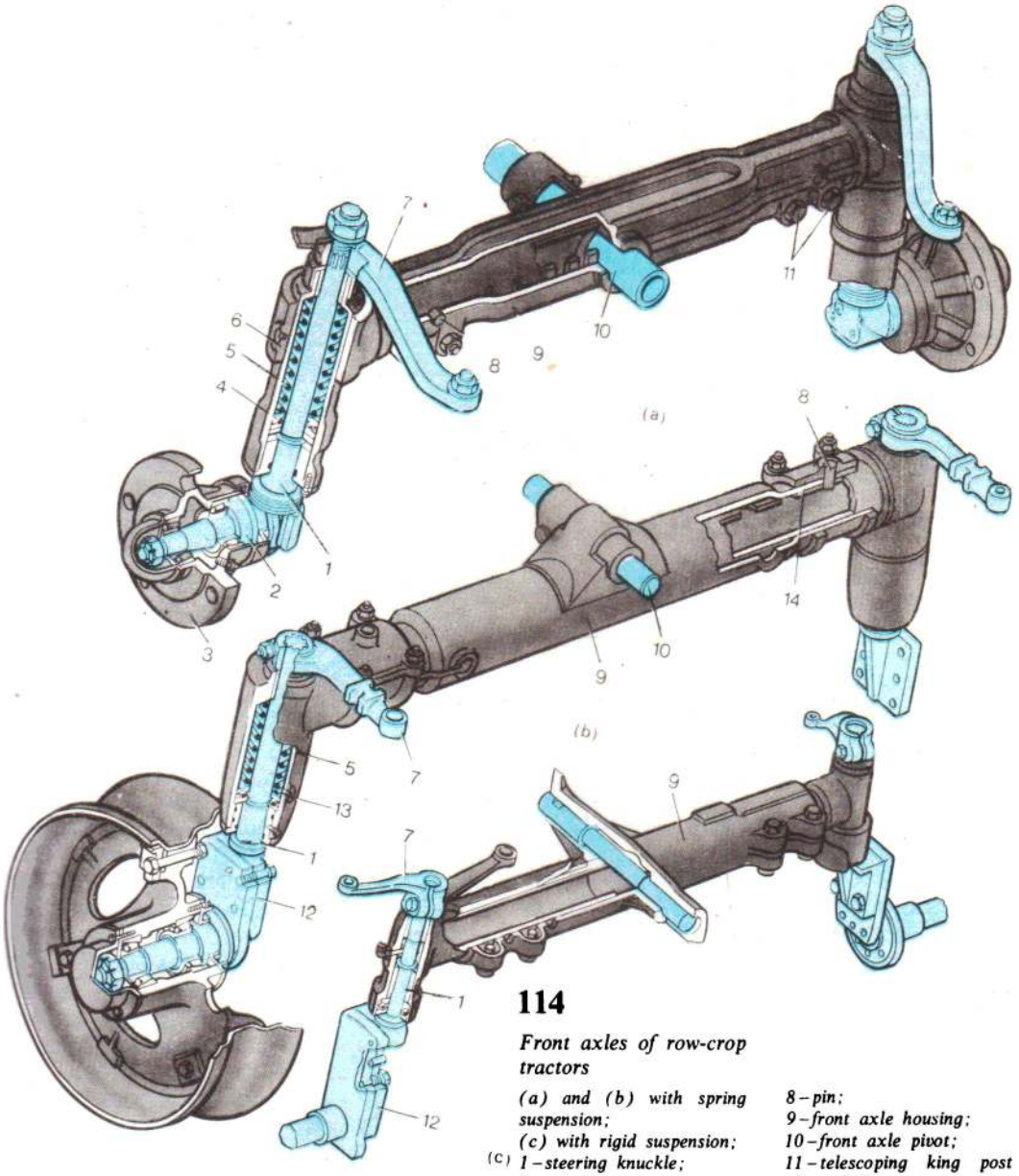
The kingpins are tilted from the vertical forward or backward (Fig. 113*b*) and also inward toward the center of the truck (Fig. 113*c*). The forward or backward tilt of the kingpins is called caster. Caster provides directional steering stability, for it helps to keep the steerable wheels pointed straight ahead. The inward tilt of the kingpins is referred to as kingpin, or steering-axis, inclination. It helps provide steering stability, reduces steering effort, and decreases tire wear.

To reduce shocks transmitted to the steering mechanism and relieve the outer bearings of the front wheel huds, the wheel spindles are tilted downward from the horizontal. This makes the wheels tilt outward at the top. The tilt of the front wheels from the vertical is termed camber.

The front wheels are set so that the distance between their tires is less at the front than at the back. The amount, in millimeters, by which the front of a front wheel points inward is termed toe-in. The purpose of toe-in is to ensure parallel rolling of the front wheels when the truck moves forward and thus reduce the slipping and wear of the tires.

The kingpin inclination and wheel camber are not adjusted, whereas toe-in is adjusted by changing the length of the steering knuckle tie rods.

The rear suspension of a truck comprises two main leaf springs provided each with an auxiliary, or overload, spring. The front ends of the main springs are rigidly connected to the truck frame by wrapper eyes, while their rear ends are free to slide over their bearings. The main springs, together with their associated auxiliary springs, are held at their center to the rear axle housing by U-bolts. The ends of the auxiliary springs have no eyes and are arranged to slide freely over their bearings. These springs come into operation only when the load on the



114

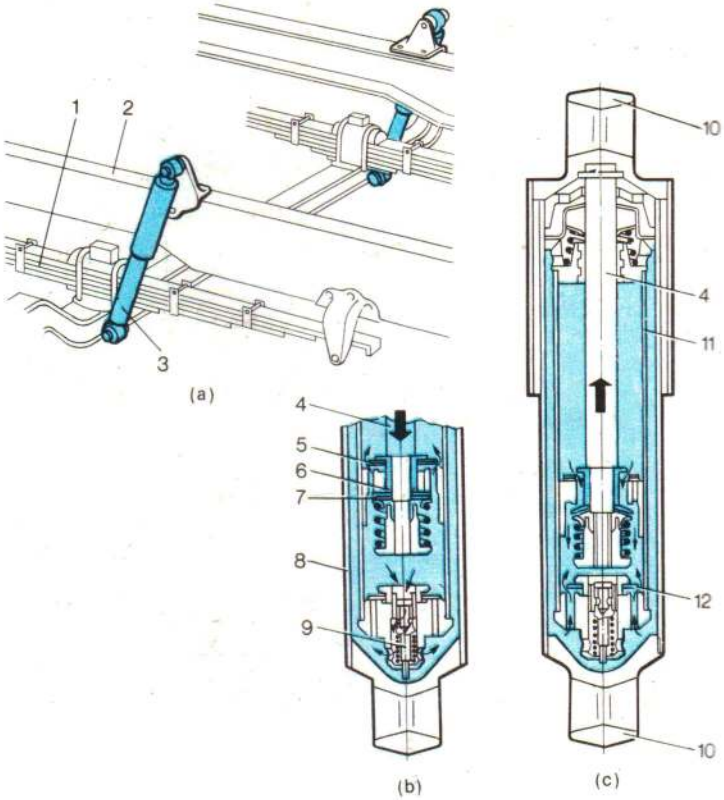
Front axles of row-crop tractors

(a) and (b) with spring suspension;
(c) with rigid suspension;
1 – steering knuckle;
2 – spindle;
3 – wheel hub;
4 – steering knuckle thrust bearing;
5 – spring;
6 – telescoping king post;
7 – steering knuckle arm;
8 – pin;
9 – front axle housing;
10 – front axle pivot;
11 – telescoping king post clamp bolt;
12 – built-up steering knuckle flange;
13 – lubricator;
14 – telescoping king post clamp

115

Shock absorber

(a) external view;
(b) compression stroke;
(c) rebound stroke;
1 – leaf spring;
2 – frame;
3 – shock absorber;
4 – rod;
5 – compression relief valve;
6 – piston;
7 – rebound relief valve;
8 – cylindrical fluid reservoir;
9 – check valve and spring;
10 – bushing;
11 – hydraulic cylinder;
12 – intake valve



real axle becomes too heavy for the main springs to cope with alone.

The front suspension of a row-crop tractor (Fig. 114*a*) consists of two coil springs *5* that are arranged inside hollow king posts *6* to support steering knuckles *1* pivoted to the king posts. The bottom ends of the springs are supported by steering knuckle thrust bearings *4*, and their other ends rest against the top wall of the king posts. The steering knuckle pivots turn in bushings pressed into the king posts.

The detachable bolted connections between the wheel spindles and steering knuckle flanges *12* (Fig. 114*b*) allow the clearance of the tractor to be adjusted. To absorb shocks that would result if the wheels actually moved up far enough to compress the springs completely, use is made of rubber bumpers mounted at the bottom part of the steering knuckles.

The king posts are welded to telescoping half axles sliding inside front axle housing *9*. Each half axle is provided with a series of holes spaced 50 mm apart. These holes enable the track width of the front wheels to be adjusted within certain limits by changing the position of the half axles in the front axle housing. The half axles are locked in position by pins *8* that pass through holes in the rear axle housing and half axles.

Splined to the top ends of steering knuckle pivots are steering knuckle arms *7*.

The front axles of some row-crop tractors have a rigid suspension (Fig. 114*c*). In this case, the pneumatic tires of the front wheels play the part of elastic suspension of a sort.

SHOCK ABSORBERS (Fig. 115) damp the oscillations of the springs that result from the wheels hitting bumps or holes. Both tractors

and automobiles use double-acting, or two-way, hydraulic shock absorbers of the telescope type.

The shock absorber consists of hydraulic cylinder *11*, piston *6* with rod *4*, cylindrical fluid reservoir *8*, and valves. The upper end of the rod is connected to a bracket held to the vehicle frame, and the lower part of the fluid reservoir is fixed to the spring whose oscillating action is controlled by the shock absorber. The fluid reservoir of the shock absorber is filled with a mixture of 50% transformer oil and 50% turbine oil, or with shock absorber fluid.

In operation, the shock absorber lengthens and shortens as the wheel meets irregularities in the road. As it does this, the piston inside the shock absorber moves up and down in the cylinder filled with fluid. Movement of the piston puts the fluid under high pressure and forces it to flow through small calibrated openings in the piston. Since the fluid can pass through these openings only slowly, the fluid slows the motion of the piston. This, in turn restrains the movement of the spring. The double-acting shock absorbers do this on both compression and rebound of the springs.

When the wheel hits a bump, the spring compresses and the shock absorber shortens (Fig. 115*b*). Piston *6* moves down. The fluid contained in the cylinder space below the piston is forced to flow into the space above the piston through the calibrated openings in the piston and compression relief valve *5*. At the same time, the fluid pressure in the space below the piston causes intake valve *12* to close. When the wheel receives a sudden severe shock, the fluid pressure in the shock absorber could go so high that it would rip open. To prevent this, check valve *9* opens when the internal pressure gets excessive, and the fluid flows from the cylinder into the fluid reservoir.

When the spring expands after the wheel passes the bump, the shock absorber lengthens (Fig. 115*c*). The piston moves up. A high pressure is applied to the fluid contained in the cylinder space above the piston, which closes the compression relief valve and opens rebound relief valve *7* in the piston. The fluid now is forced to flow into the space below the piston through the rebound relief valve and the calibrated openings in the piston. If a depression is produced in the space below the piston on its rebound stroke, intake valve *12* opens to let in some fluid from the fluid reservoir.

13.2. Wheels

Modern wheeled tractors and automobiles use pneumatic-tired disc wheels. As a result of the driving wheel tires gripping the road, the rotary motion of the wheels is transformed into the translational motion of the tractor or automobile.

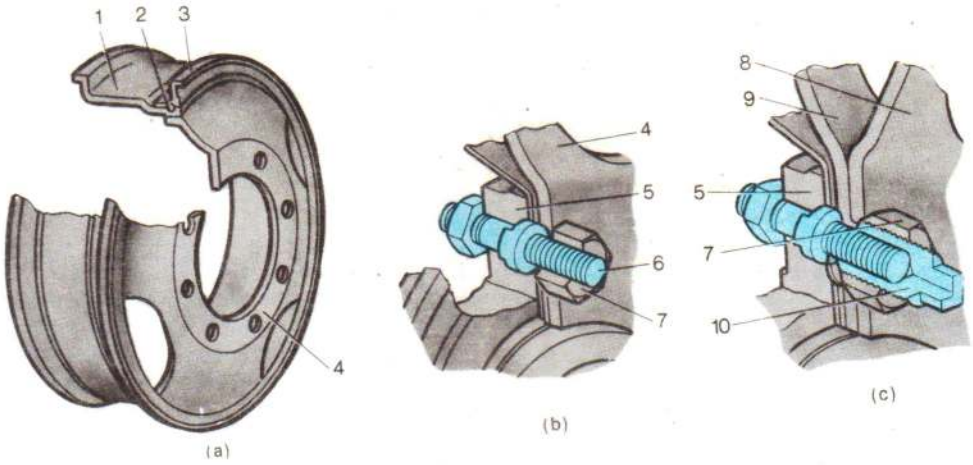
According to their purpose, wheels are classified as driving, driven steerable, and combination (both driving and steerable) types.

Trucks and general-purpose wheeled tractors have all their wheels of one and the same size. Row-crop tractors have their rear wheels larger than the front wheels. The rear wheels carry the major proportion (up to 70%) of the load due to the weight of the tractor, which provides for better traction. The front wheels are loaded lighter, and this makes them easier to turn and provide good directional steering stability, which is essential for row-crop work.

A TRUCK WHEEL (Fig. 116*a*) consists of disc *4* and flat base rim *1* that is welded to the disc. One flange of the rim is made integral with it, while the other flange is formed by detachable side ring *3* that is held to the rim by split lock ring *2*. Some truck wheels use only one split ring on the rim, which doubles as a side ring and a lock ring.

The wheel disc is provided with holes for mounting the wheel on the wheel mounting bolts, or wheel studs, on the wheel hub (Fig. 116*b*), where it is fixed by nuts *7*. Both the holes and the nuts are tapered to ensure exact location of the wheel on its hub. The rear driving axles of trucks carry two wheels at each end. The inner wheels are held to the hubs by cap nuts *10* (Fig. 116*c*) that are threaded both on the inside and on the outside, and the outer wheels are mounted on the cap nuts and fixed in place by taper nuts screwed on the cap nuts.

The wheel nuts on the right side of the truck



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Wheel

(a) construction;
(b) front wheel mounting;
(c) rear wheel mounting;
1 – flat base rim;
2 – wheel lock ring;
3 – wheel side ring;
4 – wheel disc;
5 – wheel hub;
6 – wheel mounting bolt (wheel stud);
7 – wheel nut;
8 – outer wheel disc;
9 – inner wheel disc;
10 – cap nut

have right-hand threads, whereas the nuts on the left side of the truck are threaded left-hand. The reason is to make the forward rotation of the wheels tend to tighten the nuts, not loosen them, and thus prevent them from working loose on acceleration and braking.

An automobile pneumatic tire (Fig. 117*a*) consists of casing *1*, inner tube *6*, and flap *3*. The tire casing comprises tread *4*, side walls *5*, and beads *7*. Tires for good roads use small tread patterns, while those for bad roads or cross-country service, large tread patterns.

The inner tube is made in the form of a hollow elastic rubber doughnut that is inflated with air after it is installed inside the tire and the tire is put on the wheel rim. The inner tube is inflated (or deflated, if necessary) through tire valve (Fig. 117*b*) that consists of housing *11*, valve inside *9*, and cap *10*. The valve housing is made of brass in the form of a flanged tube that is mounted in the inner tube by means of a washer and a nut and sticks out through a hole in the wheel. Some tire valve housings are of composite construction: the upper part is made of brass and the lower part, of rubber that is vulcanized on to the inner tube. The valve inside is a check valve that opens to let air in the inner tube when an air hose is applied to the valve. When the valve is closed, spring pressure and air pressure inside the tube hold the valve on its seat. It includes core *8* with a rubber ring, a plunger pin, and a spring. The valve inside is screwed in the tire valve housing and is closed by the cap screwed on the housing.

THE CONSTRUCTION OF THE DRIVING AND STEERABLE WHEELS of a row-crop tractor is shown in figure 118. Each wheel comprises hub *8*, disc *9* with rim *7*, and tire *5* with inner tube *6*. The rim is welded to the disc and the disc is bolted to the hub.

The driving wheel tires are of low-pressure type and have heavy tread bars for better traction.

The driving wheel hub is keyed to axle shaft *1* and is fixed in place by means of bolted-on insert *3* with worm *2* whose threads mesh with the rack teeth cut in the half axle. By turning the worm one can change the position of the wheel on the axle shaft to obtain the desired track width. Before doing this, it is necessary to jack up the rear part of the tractor to clear the

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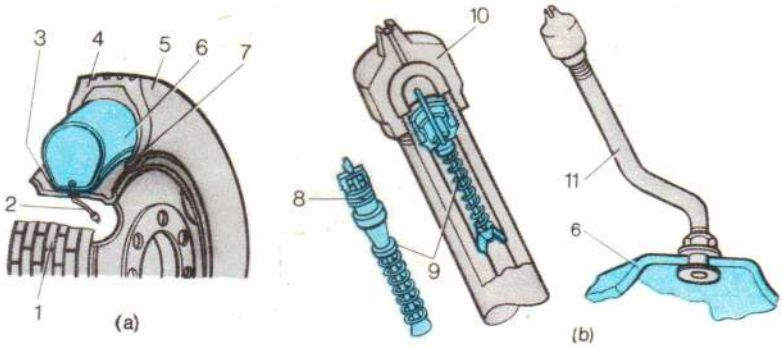
(a) Automobile tire and (b) tire valve

1 – casing;
2 – valve;
3 – flap;
4 – tread;
5 – side wall;
6 – inner tube;
7 – bead;
8 – valve core;
9 – valve inside;
10 – valve cap;
11 – valve housing

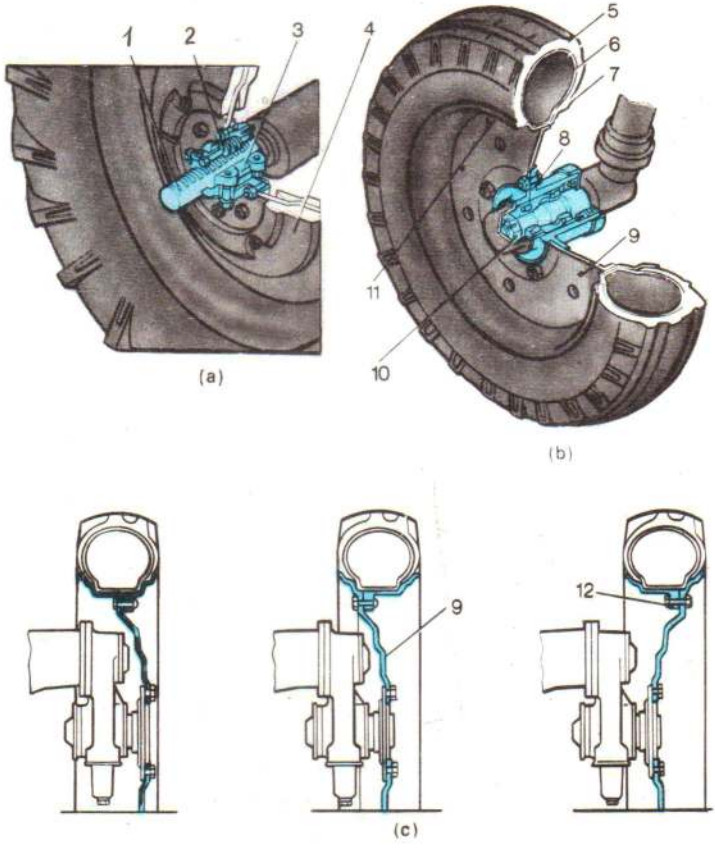


118

Row-crop tractor wheels

(a) driving wheel (MT3-80 Model tractor); (b) steerable wheel; (c) illustrating the change of driving wheel track width (T-40M and T-25A Model tractors);

1 – axle shaft;
2 – worm;
3 – insert;
4 – wheel weight;
5 – tire;
6 – tire inner tube;
7 – rim;
8 – hub;
9 – disc;
10 – adjusting nut;
11 – tire valve;
12 – rim lug



wheels of the ground and loosen the bolts that hold the inserts to the wheel hubs. Should this adjustment prove insufficient, the track width can further be increased by placing the wheels with the concaves of their discs facing inwards.

On some row-crop tractors, the rear wheel discs are bolted to lugs *12* welded on the wheel rims. In this case, the track width can be chang-

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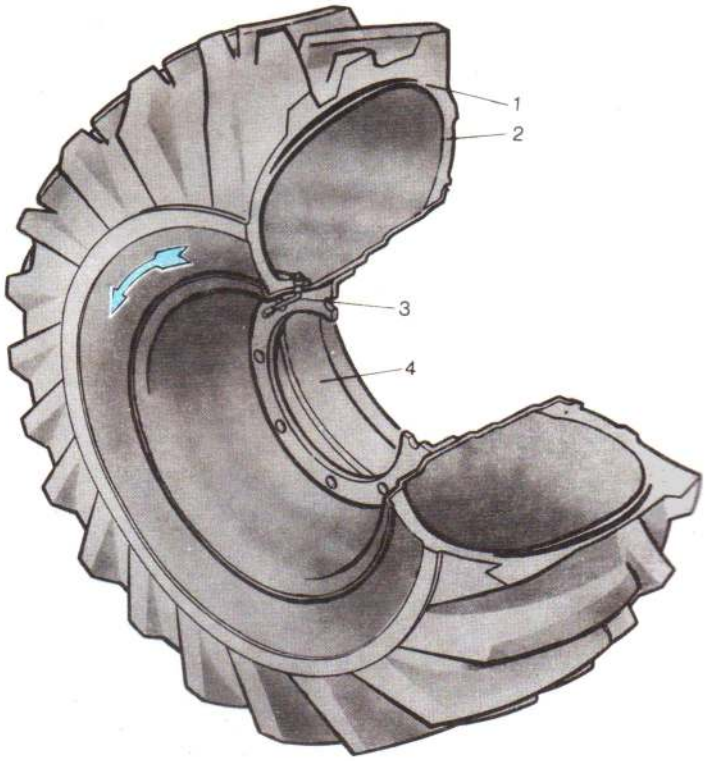
General-purpose tractor wheel

1 – tire casing;
2 – tire inner tube;
3 – tire valve;
4 – wheel disc



ed by bolting the discs in alternative positions to the lugs. Also, the concave wheel discs may be used either with the concave facing inwards or outwards.

The hub of the front steerable wheel is supported by two taper roller bearings mounted on the steering knuckle spindle and fixed in place by horned nut *10* which is also used for adjusting the preload on the bearings. The bearings are lubricated with grease put in the hub. In service, grease is injected into the hub through a lubricating nipple. The front-wheel pneumatic tire consists of a casing and an inner tube. For better wheel grip, the tire is provided with grousers.

To improve traction, wheel weights *4* are used on the driving wheels. Also, the inner tubes of the driving-wheel tires are filled 3/4 full with water. In frosts, a 25% solution of calcium chloride, whose freezing point is around – 30°C, is used instead of water. After filling the inner tubes with water or solution, the tires are inflated with air to their normal inflation pressure. When the tractor is used for transport purposes, the wheel weights should be removed and the liquid drained from the rear-wheel tires.

Tires should be mounted on wheel rims on a clean floor, so as to prevent dirt from getting into the tires. The sequence of operations is as follows.

Use tire irons to put one bead of the tire on the rim. Wipe dry the inner tube and sprinkle it with talcum powder. Insert the tire valve in the hole in the rim, place the tube inside the tire. smooth it out, and inflate to 1/4 to 1/3 normal pressure. Then use the tire irons again to put the second bead of the tire on the rim, working in both directions from the spot opposite the tire valve, and inflate the tire to normal pressure.

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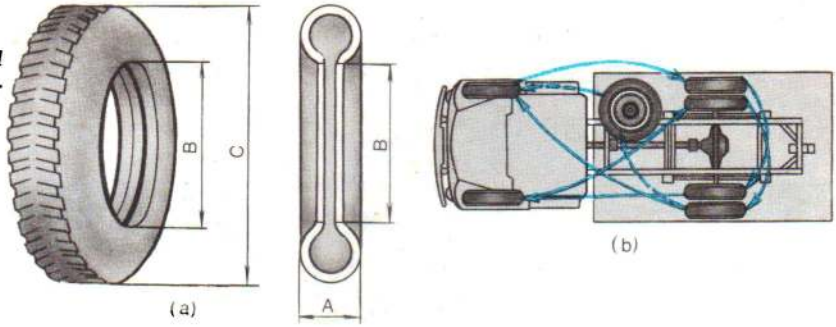
(a) Tire dimensions and (b) tire (wheel) rotation pattern

A – section width;
B – inside (rim) diameter;
C – outside diameter



If it is necessary to demount a tire, proceed in the reverse order.

To facilitate tire inflation, tractors are outfitted with a special device that allows one of the engine cylinders to be used as an air compressor. To inflate a tire, the device is installed in place of one of the fuel injectors, the air hose of the device is applied to the valve of the tire, and then the engine is run at a slow speed and the tire is inflated to the required pressure.

THE WHEELS OF GENERAL-PURPOSE TRACTORS. These tractors use interchangeable single wheels with low-pressure tires (Fig. 119). Each wheel includes tire casing *1*, tire inner tube *2*, and disc *4* that is mounted on the eight wheel studs of the wheel-hub reduction gear. When the wheels are installed with their tire valves *3* facing inwards, the track width is 1860 mm, and when they are installed with the valves facing outwards, 1680 mm. To change over from the wide to the narrow track, or vice versa, the wheels are switched from one side of the tractor to the other. The wheel tires are provided with a ground grip tread pattern.

Each automobile of wheeled tractor uses tires of a definite size (Fig. 120*a*) only. Tire dimensions are expressed in millimeters and marked on the side wall of the tire. The first number in the size designation of a tire means the section width and the second, preceded by a hyphen, the inside, or rim, diameter of the tire. The letter R added to the size designation means that the tire is of radial construction. In such a tire, layers of cord, called plies, run parallel to one another and perpendicular to the tire bead. In contrast to ordinary bias-type tires, in which the plies are crisscrossed, one layer running diagonally one way and the other layer running diagonally the other way, radial tires are more wear resistant.

Trouble-free operation of automobiles and wheeled tractors largely depends on the condition of the tires. Therefore, during operation, one should adhere to the following rules.

Prevent fuel and/or oil from getting onto the tires. Clean the tires regularly from dirt and remove all foreign articles, such as stones, from the treads. Do not apply brakes sharply, never start away from rest with a jerk, and avoid making sharp turns, for all this causes uneven wear of the tires. Do not allow excessive slipping of the driving wheels. When preparing your tractor or automobile for a long-term storage, jack up the wheels and put trestles under the axles or frame to relieve the tires.

The service life of tires is expressed in terms of their mileage. For most bias (ordinary) truck tires, the guaranteed mileage amounts to 50 000 km. Observing the above rules will help prolong the useful service life of tires.

The rotating wheels of an automobile or tractor develop great centrifugal forces. If the mass of a wheel is nonuniformly distributed around the circumference of the wheel, the wheel will tend to move off center, thus accelerating the wear of its tire. If a wheel is out of balance, one or more weights are installed on the wheel rim.

The amount of wear a tire gets depends on its location on the automobile. For example, the right rear tire wears about twice as fast as the left front tire. This is because roads are slightly

crowned (higher in the center) and also because the right rear tire is driving. The crown causes the automobile to lean out a little, so the right tires carry more weight. The combination of this and carrying power through the right rear tire causes it to wear faster. To equalize wear as much as possible, tires should be rotated any time wear is noticeable and at the mileage specified by the automobile manufacturer. One manufacturer recommends rotating tires according to the pattern shown in Fig. 120*b* every 5 000 to 6 000 km.

13.3. Running Gear of Crawler Tractor

Tracks have a number of advantages over wheels. These include reduced soil pressure and increased traction on soft, loose soil surfaces that have low strength. Also, tracks result in the best relative performance as compared with pneumatic tires when the tractor is operating at nearly maximum drawbar pull on soft, loose soil surfaces. However, the running gear of crawler tractors is more complex than that of wheeled tractors. Besides, crawler tractors cannot be allowed to use asphalt roads as freely as wheeled tractors do.

The running gear of a crawler tractor consists of an undercarriage, tracks, and suspension.

THE UNDERCARRIAGE OF A CRAWLER TRACTOR is a welded frame (Fig. 121). It is intended to support all the component parts of the tractor and is, in turn, supported by the tracks. The main components of the frame are two frame girders, or side members, *4* that are rigidly joined from below by front cross member *7* and rear cross member *8*. Each frame girder is welded from two channel sections. At the front and rear, the frame girders are joined by axles. Pads *6* welded to the frame girders serve to support the engine rear mountings. The engine front mountings are supported by brackets *5* welded to front axle *2*. Welded to the frame girders are rear brackets *9*, track idler adjusting rod anchors *10*, track support roller brackets *11*, track idler bracket bearing carrier *13*, implement-attaching linkage support brackets, etc.

Frame cross members *7* and *8* terminate in hollow end pieces with bored holes that accommodate bogie axles *12*. The end pieces are split, so that the bogie axles can be clamped in them by means of bolts.

THE TRACK ASSEMBLIES (Fig. 122) include track adjusting mechanism *1*, suspension *4*, track support, or carrier, rollers *3*, track drive sprocket *6*, and track chain *5*.

The track chain consists of a series of track links hinged together to form an endless loop. Each track link is a shaped casting of strong steel. It has four lugs with track pin holes on one side and three such lugs on the other side. Each lug is provided with a horn on the underside. The track links of swamp tractors are wider than those of general-purpose crawler tractors.

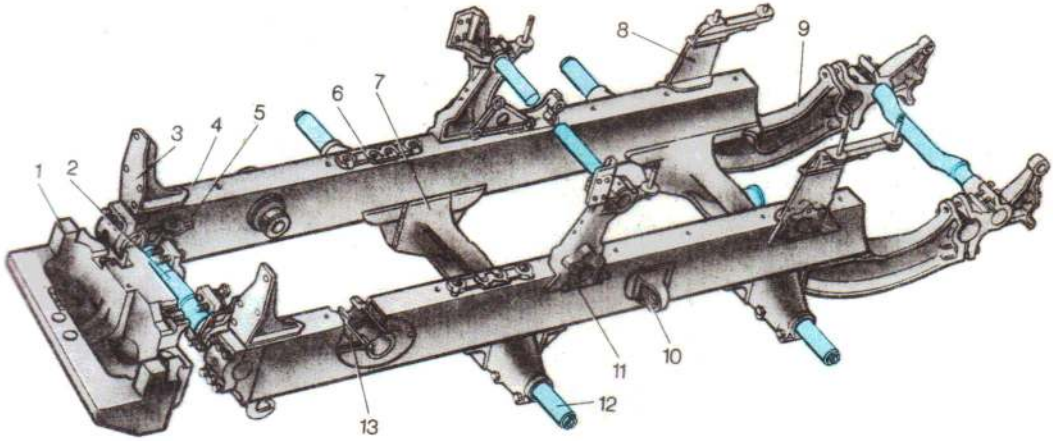
The track links are hinged together by means of hardened steel track pins that are passed through the holes in the track link lugs. The track pins have a head at the outer end and a pin hole at the inner end.

The track drive sprocket has 13 teeth whose pitch is half that of the track links. Therefore, during each revolution of the sprocket, its teeth operate by turns, and their wear is thus reduced.

THE TRACK ADJUSTING MECHANISM (Fig. 123*a*) serves to adjust the track tension. It includes track idler *7*, track idler bracket, or shackle, *13*, track idler compression springs *4*, and track idler adjusting rod *3*.

The track idler, also known as the track adjusting wheel, is fabricated from steel. The windows between the spokes of the track idler reduce its weight and make it more difficult for dirt to stick to it.

The track idler is supported by two taper roller bearings whose outer cones are press-fitted in the bores in the track idler hub. The inner cones of the bearings are mounted on the track idler spindle held to the track idler bracket and are kept from moving axially by two nuts *8* that are screwed on the threaded end



121

Crawler tractor frame

1 – balancing weight;
2 – front axle;
3 – radiator and forward mounting bracket;
4 – right-hand frame girder (side member);
5 – engine front support bracket;
6 – engine rear support pad;
7 – front cross member;
8 – rear cross member;
9 – rear bracket;
10 – track idler adjusting rod anchor;
11 – track support (carrier) roller bracket;
12 – bogie axle;
13 – track idler bracket bearing carrier

of the spindle. These nuts also serve to adjust the preload of the bearings.

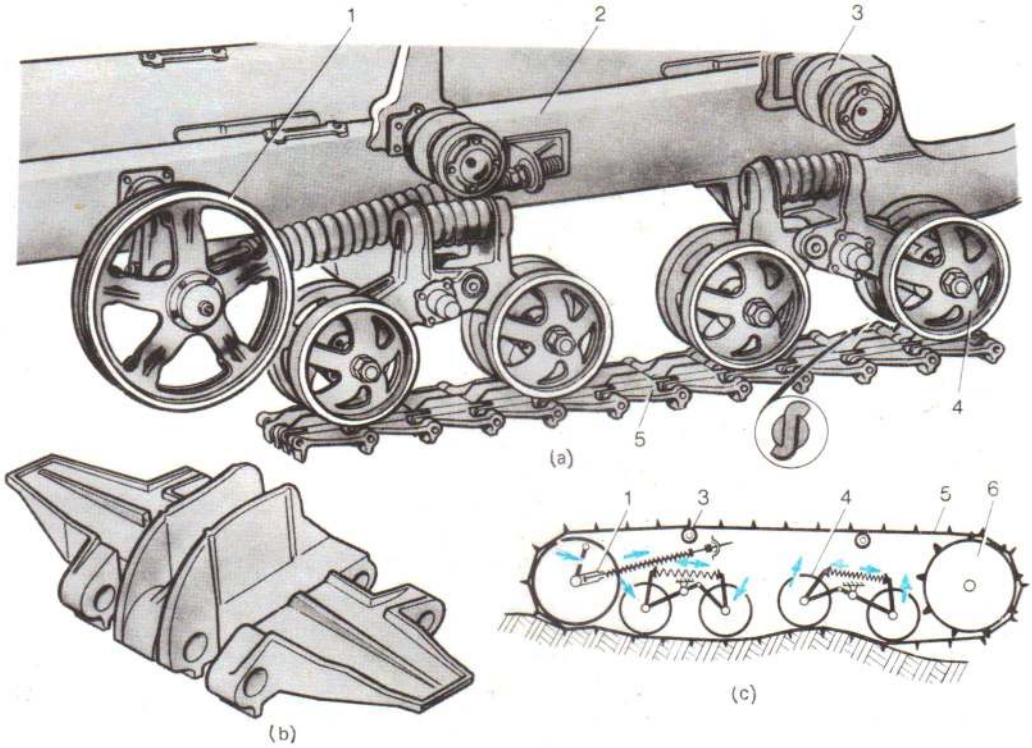
The bearings are lubricated with oil which is poured in the track idler hub through a hole in the hub cap. To prevent leakage of oil from the hub, a sealing gasket is used between the hub and the cap and a sealing arrangement at the back of the hub. The arrangement consists of a housing, sliding ring *9*, fixed ring *10*, and spring *12* placed in a rubber boot.

The journals of the track idler bracket *13* can freely turn, when the tractor is running or when the track tension is being adjusted, in cast-iron bearing bushings pressed in the bearing carrier that is welded to the frame girder.

The purpose of the track idler compression springs is to keep the track tight and protect the track idler and the track from overloads. The springs are held compressed between two retainers on track idler adjusting rod *3*. Spring retainer *2* is made in the form of a yoke and is connected to lug *1* that is bolted to the track idler bracket. The springs push the outer end of the track idler adjusting rod against its anchor on the tractor frame, a ball pivot being used between the rod and the anchor.

When the track meets a bump, the track tension increases and the track idler is pushed back. This causes the track idler bracket to turn in its bushings in the tractor frame and push back spring retainer *2*. The spring retainer slides along the track idler adjusting rod and compresses the track idler compression springs still more. This action absorbs the shock received by the track. After the track passes the bump, the springs expand and return the track idler to its initial position.

The spring compression is adjusted by changing the position of nut *5* screwed on the track idler adjusting rod. The track tension is adjusted by means of nut *6*. Turning the nut counterclockwise will cause the track idler adjusting rod to move, together with the track idler, forward, thus tightening the track. Once the track tension is adjusted properly, the adjusting nut is locked in position by means of a lock nut.



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Track assembly

(a) construction;
(b) track link of a swamp tractor;
(c) schematic diagram;
1 – track adjusting mechanism;
2 – frame;
3 – track support (carrier) roller;
4 – suspension;
5 – track chain;
6 – track drive sprocket

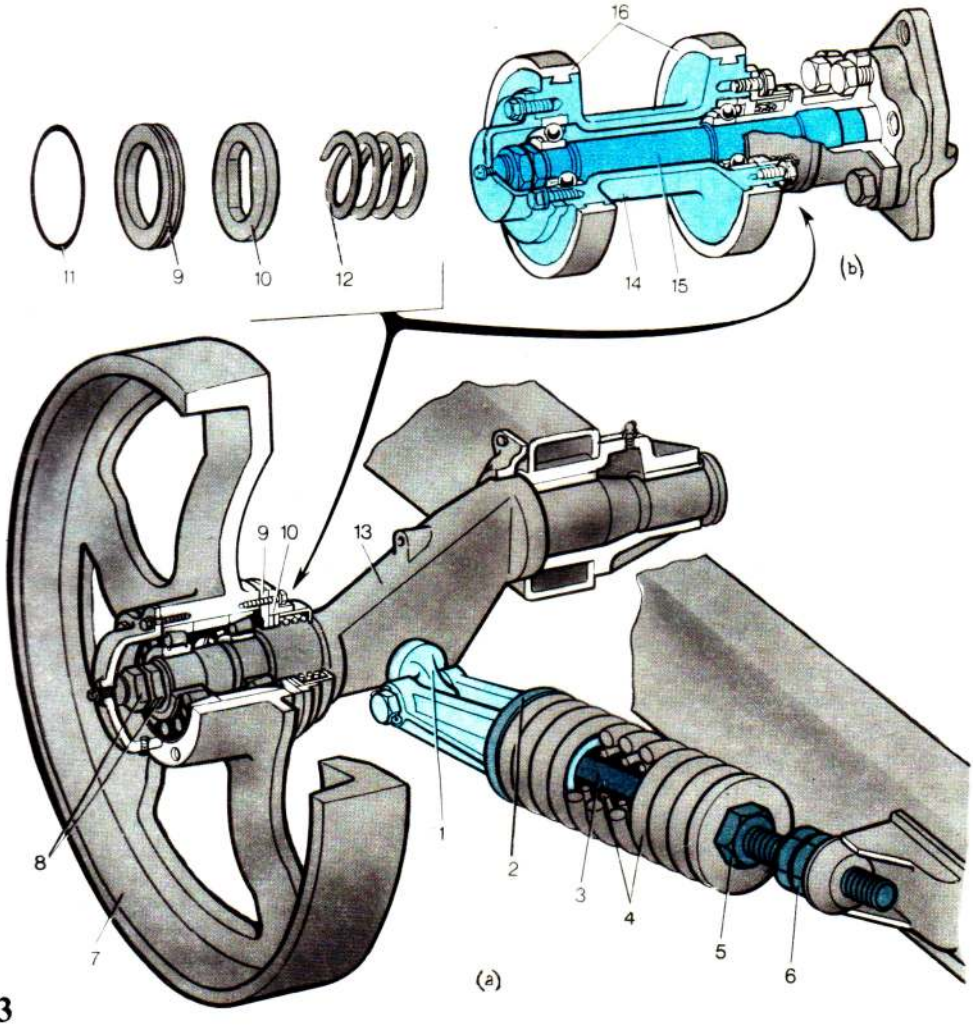
THE TRACK SUPPORT, OR CARRIER, ROLLERS (Fig. 123*b*) prevent the tracks from sagging too much and swaying sideways. There are two such rollers on each side of the tractor frame. The main parts of a track support roller are hub *14* and spindle *15*. The support roller hub is cast in iron in the form of a hollow cylinder carrying two rims. Mounted on the rims are replaceable solid rubber tires *16*. The roller is supported by two ball bearings mounted on the spindle that is press-fitted in its bracket.

The bearings are lubricated with oil poured in the roller hub through a hole in its cap. This hole also doubles as an overflow hole and a drain hole. When filling the hub with oil, the roller is turned so as to make the hole lie above its center; when checking the oil level in the hub, the hole is aligned with the horizontal axis of the hub, and when draining oil from the hub. the roller is turned with the hole in its lowermost position.

THE SUSPENSION supports the frame of the tractor upon its tracks and ensures smooth running. The sprung suspension of the tractor comprises four suspension bogies (Fig. 124), two bogies being used on each side of the tractor.

The suspension bogies are pivoted on the tractor frame by means of bogie axles *6* that are clamped in the end pieces of the frame cross members. Each suspension bogie consists of two bogie, or track wheel, arms *1* and *5*, which are supported by bogie, or track, wheels *10*, and bogie spring *2* installed between the arms.

The bogie arms are cast in steel and have



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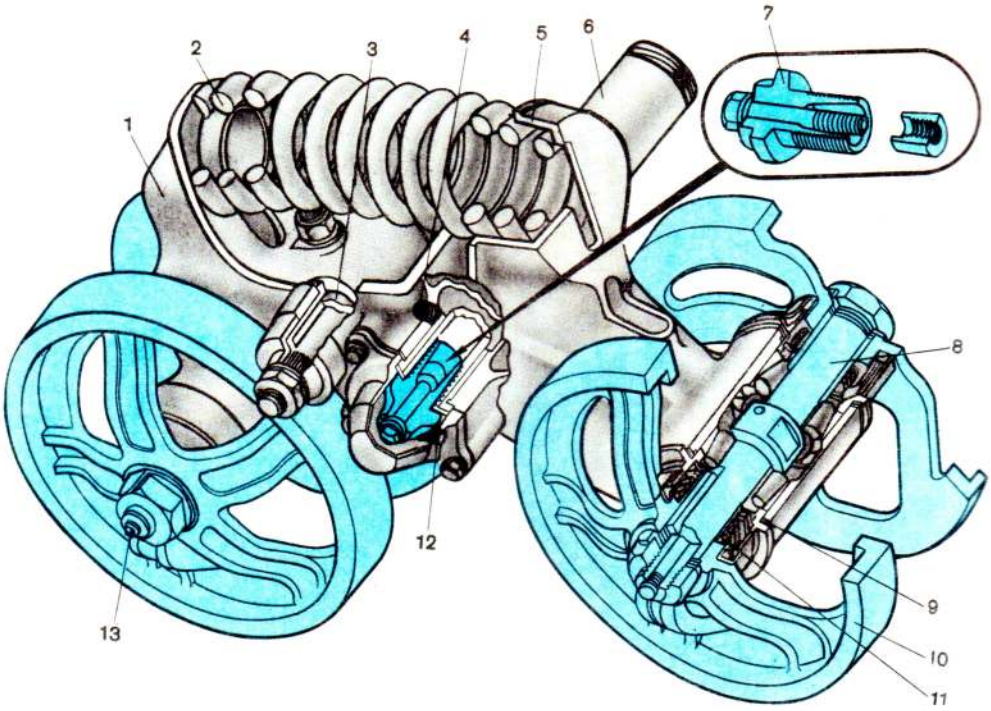
(a) Track adjusting mechanism and (b) track support (carrier) roller

1 – track idler bracket lug;
2 – spring retainer;
3 – track idler adjusting rod;
4 – track idler compression springs;
5 – spring compression adjusting nut;
6 – track tension adjusting nut;
7 – track idler;
8 – adjusting and lock nuts;
9 – sliding sealing ring;
10 – fixed sealing ring;
11 – rubber sealing ring;
12 – spring;
13 – track idler bracket (shackle);
14 – track support roller hub;
15 – track support roller spindle;
16 – solid rubber tires

a complex shape. The inner end of the longer, outer arm *5* of the bogie is forked and hinged to the inner end of the shorter, inner arm *1* by means of hollow pivot pin *3*. During assembly, the suspension bogies are mounted on the tractor so that their inner arms are pointed toward the center of the tractor.

The suspension bogie is freely supported on its axle *6* by two hardened steel bushings that are pressed in the central hole in its outer arm. The arm, hence the bogie as a whole, is kept from moving sideways on the axle by a thrust



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Suspension bogie

1 – bogie inner arm;
2 – bogie spring;
3 – bogie arm pivot pin;
4 – oil filler plug;
5 – bogie outer arm;
6 – bogie axle;
7 – combination collet-nut;
8 – bogie wheel spindle;
9 – adjusting shims;
10 – bogie (track) wheel;
11 – sealing arrangement;
12 – overflow hole plug;
13 – plug

washer which is pressed against the end face of the axle by combination collet-nut *7*.

The rubbing surfaces of the bogie axle and bushings are lubricated with oil poured in the central cavity of the bogie outer arm through the hole closed by plug *4*. The oil level in the cavity is controlled by the overflow hole closed by plug *12*.

The upper ends of the bogie arms are provided with cup-shaped hollows in which fit the ends of the heavy coil spring of the bogie. The spring tends to turn outward the bogie arms on their pivot pin and thus move down the bogie wheels carried on the lower ends of the arms, whereas the weight of the tractor tends to push down the bogie arm pivot pin and compress the spring. In this way, the weight of the tractor is carried to the bogie wheels and thence to the tracks through the coil spring which makes the tractor suspension elastic.

Carried on the lower ends of the bogie arms are bosses with bored holes which accommodate the taper roller bearings that support bogie wheel spindles *8*. The bogie wheels are cast in steel and are press-fitted on the projecting ends of the spindles. The preload on the bogie wheel bearings is adjusted by means of shims *9* placed under the flanges of sealing arrangements *11*.

The bogie wheel bearings are lubricated with liquid oil that is injected through a passage drilled through the bogie wheel spindle. The outlet hole of the passage is closed by plug *13*. When injecting oil, the nozzle of the oil injector is inserted in the hole as far as it will go, and the

oil is injected until the oil flowing out through the clearance between the nozzle and the hole walls becomes clean enough.

Rubber sealing rings placed under the nuts screwed on the ends of the bogie wheel spindle and sealing arrangements *11* prevent the leakage of oil from the bogie wheel bearings and keep dust and dirt from getting into the bearings. The component parts of the sealing arrangements are interchangeable with those of the track support rollers.

13.4. Running Gear Troubles

The running gear may suffer from oil leaks. To correct the trouble, clean the leaky spot and check visually for the cause of trouble. Loose fasteners should be tightened up and worn or damaged sealing arrangement components or damaged sealing gaskets replaced.

The most common troubles of the running gear of wheeled tractors and automobiles include excessive instability (wobble) of the front steerable wheels, punctured tires, damaged wheels, and bent front axle. All these troubles are conducive to traffic accidents and therefore it is prohibited to operate vehicles showing any of the above conditions.

The instability of the front wheels may be caused by worn steering knuckle pivots and their bushings and thrust bearings or by worn or loose wheel bearings. Worn components should be replaced and loose bearings adjusted properly. To adjust wheel bearings, the wheel should be jacked up.

Inner tube leaks due to punctures and other minor injuries can be patched en route either by the cold-patch method (i.e., by cementing a rubber patch to the tube) or by the hot-patch method (i.e., by vulcanizing a patch of uncured rubber to the tube). Damaged tire casings should be repaired, if repairable, at a garage or specialized shop. Badly damaged tires should be discarded.

Wheel discs or rims may be damaged as a result of careless driving. Loose wheel mounting bolts or nuts may cause damage to the bolt holes in the wheel discs, which may render the discs irrepairable. Damaged wheels and bent front axles should be repaired.

In the course of service, suspension springs gradually weaken and their eye bolts and bushings wear down. Careless driving may result in a broken leaf in a leaf spring. Weak springs will sag, causing the tires to rub against the body of the vehicle and thus wear rapidly. Driving a vehicle with a broken spring will cause the axle to skew and will make it difficult for the driver to keep the vehicle moving straight ahead. Weak and broken suspension springs should be replaced.

Special attention should be given to the track tension in crawler tractors. Both excessive and insufficient track tension accelerate wear of the tracks and cause the tractor engine to lose power in propelling the tractor. Moreover, a loose track with badly worn links may come off the tractor.

ADJUSTING THE TRACK TENSION. To check a track for tension, place the tractor on an even and hard surface. Do it in such a way as to make tight the track section between the rear track support roller and the drive sprocket. Place a straight batten on the projecting ends of the track link pins above the track support rollers and measure the distance from the batten to the track link that sags most. This distance must be from 30 to 50 mm. Repeat the procedure for the second track. Both tracks must have an equal amount of sag.

If the track tension proves to be improper, it should be adjusted. To adjust a track for proper tension, clean the track adjusting mechanism from dirt and lubricate the threaded portion of the track idler adjusting rod with grease. Loosen the lock nut and turn the adjusting nut clockwise (when facing the rear of the tractor) to tighten the track. To loosen the track, turn the adjusting nut counterclockwise. After making adjustment, tighten the lock nut. Should the length of the threaded portion of the track idler adjusting rod prove insufficient for tightening the track properly, remove one track link from each track and make adjustment once more. Adjust each track an equal amount.

Review Questions

1. List the main component parts of the running gear of a tractor.
2. List the types of undercarriage used on farm tractors.
3. What is the purpose of the suspension of tractors and automobiles?
4. How are the track width and clearance of row-crop tractors adjusted?
5. What is the principle of operation of the telescopic shock absorber?
6. What is the difference between the driving and steerable wheels of row-crop tractors?
7. Describe the construction of automobile wheels.
8. How are tractor and automobile wheels marked?
9. List the component parts of the tire valve.
10. What are the advantages and disadvantages of tracks as compared with wheels?
11. How do the track idler compression springs operate?
12. How is the tension of a track adjusted?
13. What are the most common troubles of automobile wheels and how can they be corrected?

Chapter 14

The Steering System

The steering system enables the driver to guide the automobile or wheeled tractor down the road and turn right or left, as desired, by turning the front wheels or a half-frame (in tractors with articulated frame steering). There are two types of steering systems. These are manual and power.

14.1. Manual Steering

The manual steering system (Fig. 125) includes the steering wheel, which the driver turns to steer his vehicle, a steering gear, and a steering linkage.

The steering gear converts the rotary motion of the steering wheel into a straight-line motion, which is transmitted to the steering linkage to swing the front wheels left or right for steering, and reduces the steering effort, i.e., the effort the driver must put forth to turn the steering wheel. There are several types of steering gear: worm and roller, worm and sector, screw and nut, etc.

THE WORM AND ROLLER TYPE OF STEERING GEAR is used on some automobiles and wheeled tractors that can be steered manually. The steering gear (Fig. 126) includes triple roller *6* and globoid worm *8*, which make up a worm gearing with a high gear ratio.

The central hole of the worm is provided with serrations that mate with identical serrations on steering shaft *5*. The worm is supported by two taper roller bearings carried in bores in steering box *9*. The inner cones of the bearings are made integral with the worm. The outer cones of the bearings are clamped axially between the steering box top and bottom covers. The preload on the bearings is adjusted by means of shims placed between the box and its bottom cover *1*. The top cover fits in a bore in the steering box and forms the base of steering column *3*.

The steering shaft passes inside the steering column and is supported in its top part by a radial thrust ball bearing installed in the steering column. The shaft is hollow and houses the horn button wire. Steering wheel *4* is keyed to the tapered top end of the steering shaft and is fixed in place by a nut. The metal framework of the steering wheel is faced with plastic. The steering wheel center accommodates the horn button.

Triple roller *6* is supported by two needle bearings on a pin pressed in the holes in the boss (head) of steering arm shaft *7*.

The outer end of the steering arm shaft is supported by a bushing pressed in the side wall of the steering box, and its inner end is supported by a cylindrical roller bearing installed in the side cover of the box. The inner end of the shaft is provided with an annular groove that fits in a recess in adjusting screw *10*. The other end of the screw is provided with a socket for a special wrench. The adjusting screw is screwed in the steering box side cover and keeps the steering arm shaft from moving

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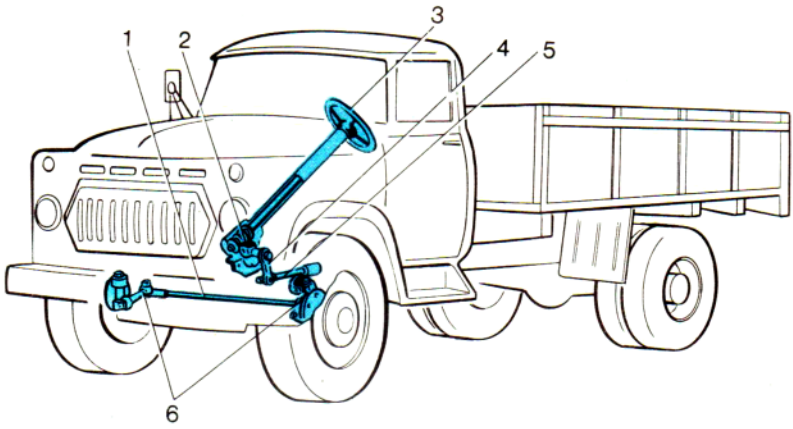
Schematic diagram of a steering system

1 – steering knuckle tie rod;
2 – steering box;
3 – steering wheel;
4 – steering arm;
5 – steering gear connecting rod (steering drag rod);
6 – steering knuckle arms



axially. The screw is locked in position by tab washer *11* whose tab fits in a slot in the screw. The washer is pressed against the cover by a cap nut screwed on the adjusting screw.

Turning the adjusting screw enables one to move the steering arm shaft endwise either way and thus change the backlash between the steering worm and the roller, hence the tilt, or play, of the steering wheel.

The outer end of the steering arm shaft has splines that mate with identical serrations in the eye of steering, or pitman, arm *16* fitted on the shaft. To ensure proper location of the steering arm on its shaft, a mark is made across their end faces. The arm is fixed on the shaft by a nut.

The steering gear is lubricated with transmission oil poured in the steering box through a hole closed by a plug. The leakage of oil from the steering box is prevented by a lip-type seal, a felt ring, and sealing gaskets.

THE STEERING LINKAGE (Fig. 126*b*) carries the movement of the steering arm to the steering knuckles. The steering linkage is constructed so as to make all the wheels of the automobile or wheeled tractor move on turns without side slipping, which ensures easy steering and minimizes tire wear. To achieve this, all the wheels must turn about a common center. Because the outside front wheel on a curve turns about a longer arc than does the inside wheel, it is therefore necessary to have the inside wheel turn at a sharper angle than the outside wheel. The difference in angles between the two front wheels when they are making a turn is referred to as the turning radius, or toe-out on turns. Toe-out on turns is obtained by making steering knuckle arms *12* closer together at their ends connected by steering knuckle tie rod *13*. Although the tie rod moves each arm an equal distance, their angular movement is unequal, and the wheels toe out. The sharper the turning angle, the more toe-out results. Steering arm *16* is linked with the steering knuckles by steering gear connecting rod *15*, also known as the steering drag rod, and steering knuckle gear rod arm *14*. The ends of the steering gear connecting rod and steering knuckle tie rod are fitted with ball joints. The lower end of the steering arm carries a pin that fits in a taper hole in the arm. The ball end of the steering arm pin fits in one of the ends of steering gear connecting rod *15*. On both sides of the ball end of pin *4* (Fig. 127), there are spherical bearing inserts *1* that are pressed against the ball by spring 2 clamped in the rod end by screw plug *3*. Such ball joints are used in all ends of the steering rods. Nowadays, rubberized polyamide inserts *6* and *7* are used instead of the springs and metal bearing inserts in the ball joints of steering linkages of automobiles and wheeled tractors. The clearance in the ball joints of the old type is adjusted by the screw plugs which, after making adjustment, are locked in position by pins or lock rings.

To reduce wear, the ball joints of the steering

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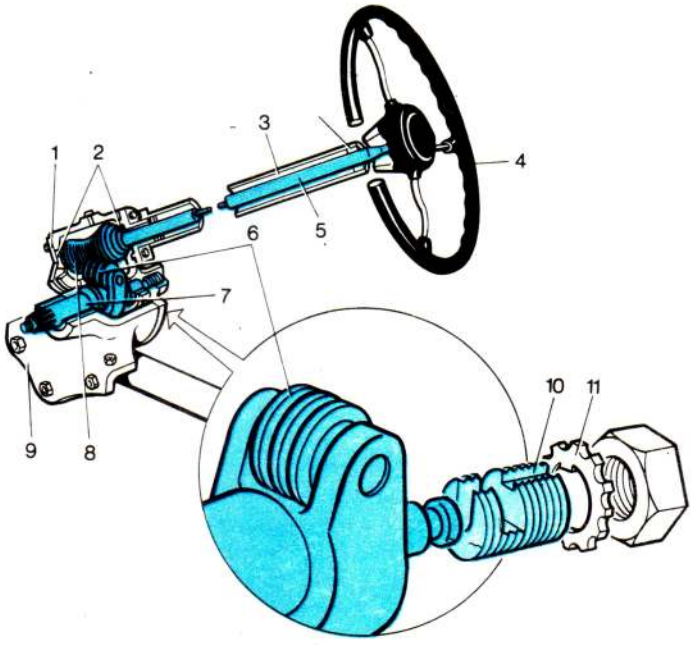
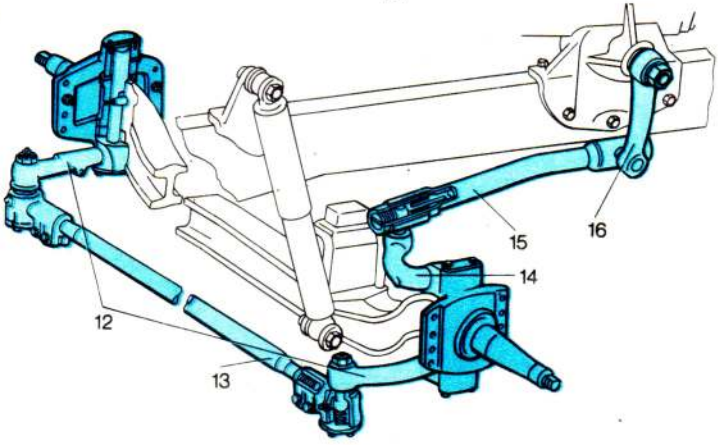
(a) Steering gear and (b) steering linkage

1 – steering box bottom cover;
2 – taper roller bearings;
3 – steering column;
4 – steering wheel;
5 – steering shaft;
6 – roller;
7 – steering arm shaft;
8 – steering worm;
9 – steering box;
10 – adjusting screw;
11 – tab washer;
12 – steering knuckle arms;
13 – steering knuckle tie rod;
14 – steering knuckle gear rod arm;
15 – steering gear connecting rod (steering drag rod);
16 – steering arm



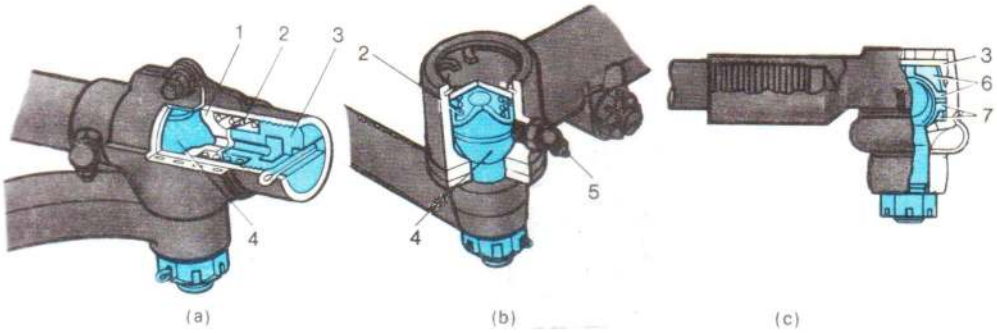
(a)



(b)

linkage are lubricated with grease injected through grease fittings, or nipples, *5*.

The system operates as follows. When the driver turns the steering wheel clockwise (right), the steering worm and roller in the steering box cause the steering arm to swing backward. As the steering arm swings back, it pulls on the steering linkage, which causes the front wheels to turn to the right. When the steering wheel is turned counterclockwise, the front wheels turn to the left.



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Steering rod ball joints

a) and (b) old type;
c) new type;
1 – metal bearing insert;
2 – spring;
3 – screw plug;
4 – pin;
5 – grease fitting;
6 and 7 – rubberized polyamide inserts

14.2. Power Steering

To reduce steering effort, some wheeled tractors and automobiles are equipped with power steering systems. The power steering system uses hydraulic pressure built up by an engine-operated pump to assist the driver in turning the front wheels. Power steering therefore is also known as the hydraulic servo, or booster, steering. Two types of power steering mechanisms are in common use – a power-assist linkage and a power-assist piston operating within the steering box. The former is known as the linkage-type power steering gear and the latter, the integral, or coaxial, power steering gear. In all power steering designs, driver "feel" is built into the system by having the driver do some of the work.

With any type of power steering, the movement of the steering wheel moves a valve which directs oil, under pressure, to a piston to help the driver turn the front wheels. The valve mechanism is designed so that the more pressure the driver applies to the steering wheel, the more hydraulic pressure is applied to the power-assist piston.

The hydraulic valve mechanism is designed to be uni-directional, that is, power assists the driver in turning the front wheels but road shocks are opposed by hydraulic pressure, and, therefore are not transmitted to the steering wheel.

The integral power steering gear (Fig. 128) is basically a worm-and-sector manual steering gear that has a hydraulic control system built into it.

The steering gear consists of steering worm *6* splined to the steering shaft that carries motion from the steering wheel and sector *8* rigidly fixed on steering arm shaft *10*, also known as the sector shaft. All parts of the steering gear are fitted into steering box *1* located concentrically about the steering arm shaft.

The hydraulic control system includes an oil reservoir built into the steering box, an engine-driven oil pump, hydraulic control valve *5*, and power-assist cylinder *4* with piston *3*.

The oil reservoir is filled with oil through the filler closed by cap *14*. The filler neck is equipped with a screen filter and an oil gauge.

The oil pump is of gear type. Its design is considered in detail in Chapter 16.

The power-assist cylinder is of double-acting type and is located in the top part of the steering box. The piston rod is connected to rack *9* that meshes with the steering-gear sector on the side opposite the steering worm.

The hydraulic control valve directs the flow of oil from the oil pump to the power-assist cylinder. It consists of body *6* (Fig. 129) with grooves and oil passages and spool valve *5* that is held to the shank of the steering worm. At

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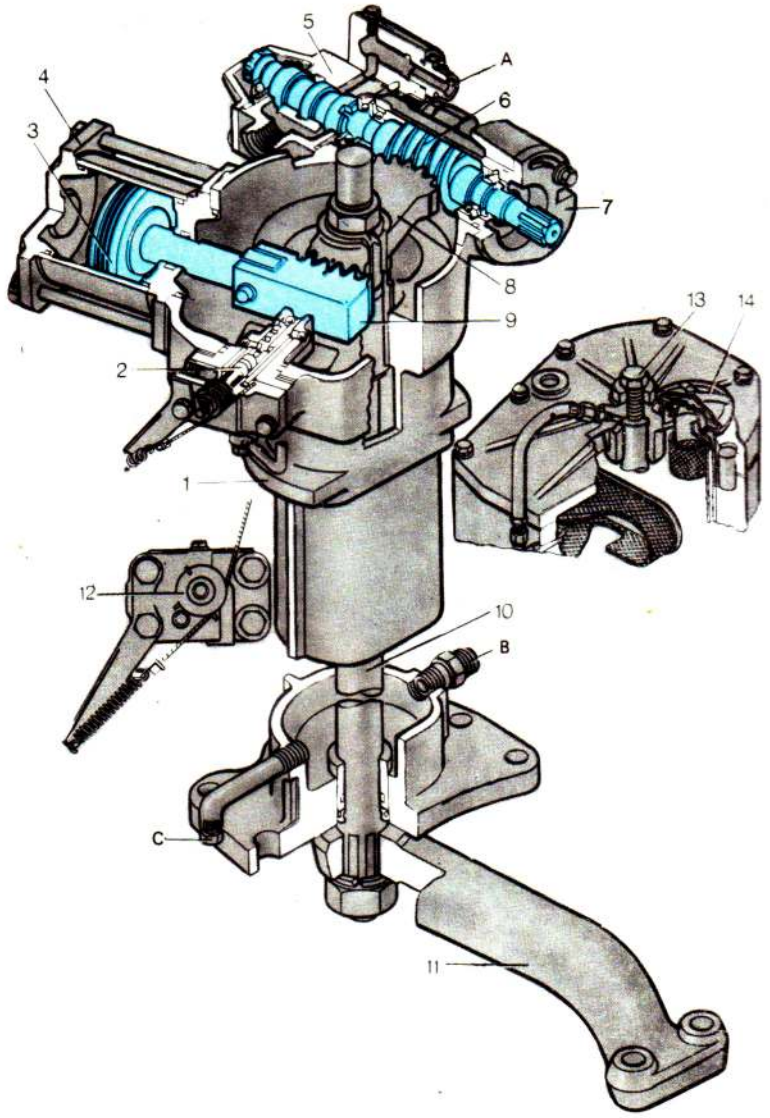
Integral power steering gear (MT3-80 Model tractor)

1 – steering box;
2 – thrust block with automatic differential lock system sender;
3 – power-assist piston;
4 – power-assist cylinder;
5 – hydraulic control valve;
6 – steering worm;
7 – adjusting eccentric bushing;
8 – steering-gear sector;
9 – power-assist piston rack;
10 – steering arm shaft (sector shaft);
11 – steering arm;
12 – automatic differential lock system control valve;
13 – stop bolt;
14 – oil filler cap;
A – pressure line inlet;
B – discharge line outlet;
C – discharge to steering box



both ends of the spool valve, there are thrust washers 7 that are acted upon by spring-loaded slide blocks *8*.

Acting upon the thrust washers, the slide blocks and their springs keep the spool valve in its neutral position when no pressure is applied by the driver to the steering wheel and the tractor or automobile is moving in the desired direction. In this case, oil flows through all the grooves of the control valve body equally because the central land of the spool valve is centered in its groove. The oil reaches both sides of the power-assist piston, and so no movement results. At the same time, pressure line *10* is made to communicate with the discharge line, so that the oil delivered by the pump returns to the oil reservoir.

Steering worm *11* can move axially a little.

for there are clearances between each thrust washer *7* and the end face of its bore in the valve body. When the driver turns the steering wheel, the steering worm is caused to turn. As the steering worm turns, its threads are thrust against the teeth of the sector, which causes the worm and the spool valve attached to it to move axially one way or the other, depending on the direction of the turn. This directs the oil from the pressure line of the pump to one of the spaces (power chambers) of the power-assist cylinder. The oil pushes piston *1* together with its rod and rack *13*, thus turning the steering-gear sector to actuate the steering linkage of the front wheels through steering arm *12* held to the vertical sector shaft. At the same time, the other space of the power-assist cylinder is connected to the discharge line, so that the oil contained in this space can be forced out by the moving piston.

As soon as the driver releases pressure on the steering wheel, the spool valve is returned to neutral by the spring pressure on its thrust washers. Equal oil pressure is then directed to both sides of the power-assist piston, and the tractor or automobile continues in the chosen direction.

The restraining force of the springs must be overcome by the driver's effort before the spool valve can move. This contributes to driver "feel".

If the power-assist system should fail, the tractor or automobile can still be steered manually, but with some difficulty. Turning the steering wheel clockwise (right) causes the steering-gear sector to turn also clockwise (as viewed from above), thus swinging the steering arm to the left. This turns the front wheels to the right.

To make the amount of oil delivered to the power-assist cylinder independent of the engine speed, use is made of excess flow valve *4* that is mounted in the control valve cover. Installed in the cover is also relief valve *9* adjusted to open at a pressure of 7.5 to 8 MPa. Both valves are sealed, and the driver is forbidden to change their setting.

In tractors equipped with an automatic differential lock system (see Chapter 12), the system is interlocked with the power steering system by means of a sender incorporated in thrust block *15* of the power-assist piston rack. When the tractor is moving straight ahead, spool valve *17* of the sender fits in a notch in rack *13*. In this position the differential is locked. When the driver makes a turn in either direction, the rack pushes the spool valve out of its notch. This makes the power chamber of the differential lock clutch actuator communicate with the discharge line to unlock the differential.

The automatic differential lock system can be overriden manually by means of control valve *14* (item 12 in Fig. 128) which is operated by a control cable connected to a control handle arranged in the driver's cab. The control handle, hence the control valve, has three positions: position I – automatic differential lock system off, position II – automatic differential lock system on, and position III – differential locked intentionally irrespective of the position of the front wheels.

Proper backlash (0.1 to 0.3 mm) between the teeth of rack *13* and steering-gear sector is adjusted by changing the thickness of the adjusting shim pack placed under the flange of thrust block *15*.

Wheeled tractors having an articulated frame are equipped with a linkage-type power steering gear (Fig. 130). In this system, power-assist cylinders *10* and *11* are arranged separately from hydraulic control valve *5* that is accommodated in a housing concentrically located about the steering column. The power-assist cylinders are mounted one on each side of the tractor and are hinged to the front half-frame at one end and to the rear half frame at the other. When the driver turns steering wheel *3* either way, hydraulic control valve *5* directs oil, under pressure, to the appropriate power chambers of the power-assist cylinders to swing rear half-frame *12* in the desired direction relative to the front half-frame. Steering gear connecting rod *8* that connects steering arm 7 with the rear half-frame provides for driver "feel".

The screw-and-nut type of integral power steering gear (Fig. 131) finds application on

some automobiles and row-crop tractors. In such power steering mechanisms, the power-assist cylinder is formed by the steering box itself.

Steering box *1* houses power-assist piston-rack *5* with teeth cut in its side surface. The teeth of the piston-rack mesh with the teeth of the steering gear sector fixed on steering arm shaft (sector shaft) *4*. Passing inside the piston-rack is steering screw *6* having a trapezoidal thread. The steering screw is linked with the steering shaft that carries the steering wheel by means of a universal-joint shaft. Screwed on the steering screw are two steering-gear nuts *9*. The nuts are pinned to the piston-rack so that they can move axially a little, but not turn, relative to the piston-rack. A precision-machined hole in the piston-rack accommodates spool valve *7*. The valve is spring-loaded on both sides, and its movement either way is limited by adjusting screws (stops) *8* that are screwed in the steering-gear nuts. On tractors using such a power steering gear, the hydraulic part of the power steering system shares a common oil tank and oil pump with the hydraulic lift system.

The oil pump forces oil through an excess flow valve and a high-pressure hose to the inlet of the control valve of the power steering gear. If the driver does not apply pressure to the steering wheel, both the piston-rack and the spool valve are in neutral, and so oil flows equally on both sides of the piston-rack and out through open discharge passages *3* to the discharge line.

When the driver makes, for example, a left turn, steering screw *6* turns counterclockwise. Steering-gear nuts *9* do not turn, being prevented from doing this by their pins, but move instead along the screw. The left-hand nut comes to rest against the piston-rack, thus deflecting the left-turn reaction ring (spring washer) *2* and closing discharge passage *3* of the left-turn power chamber *A*, while the right-hand nut moves away from the piston-rack. At the same time, adjusting screw *8* in the left-hand nut pushes spool valve *7* to the right. This opens the inlet port of the left-turn power chamber still more and fully closes the inlet port of the right-turn power chamber *B*. As a result, the oil delivered by the pump enters only the left-turn power chamber *A* and pushes the piston-rack to the right, which turns the steering-gear sector, hence the steering arm held to the sector shaft, counterclockwise to turn the front wheels to the left. The piston-rack continues moving so long as the driver turns the steering wheel, thus pressing left-hand nut *9* against the end face of the piston-rack and closing discharge passage *3* of the left-turn power chamber *A*.

As soon as the driver releases pressure on the steering wheel, both the steering screw and the steering-gear nuts stop moving, the piston-rack is forced to occupy the central position between the two nuts by oil pressure on left-turn reaction ring *2*, and spool valve *7* is returned to neutral by spring pressure. Equal oil pressure is then directed to both sides of the piston, and the front wheels continue stably in their position. A right turn is made in a similar way.

When assembling the steering gear, the central tooth of the piston-rack is placed in the central space between the teeth of the steering-gear sector.

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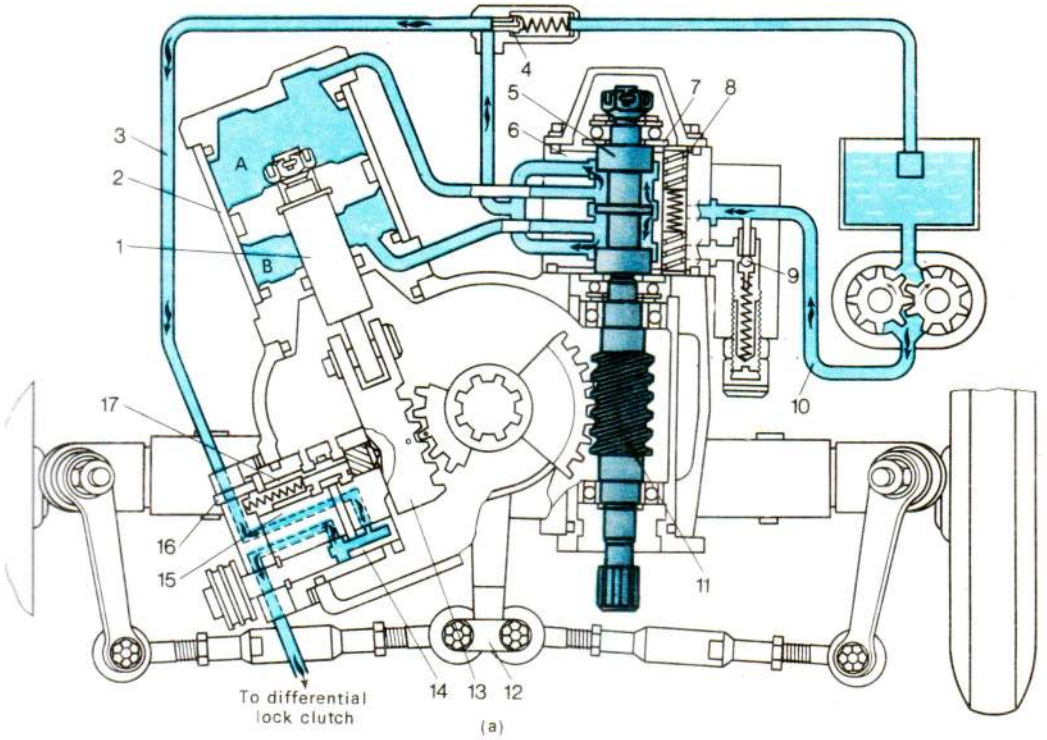
Schematic diagram of integral power steering gear

(a) steering gear control valve in neutral position;
(b) steering gear control valve in right-turn position;
(c) steering gear control valve in left-turn position;
1 – power-assist piston;
2 – power-assist cylinder;
3 – pressure line to automatic differential lock system sender;
4 – excess flow valve;
5 – spool valve;
6 – hydraulic control valve body;
7 – thrust washer;
8 – slide block;
9 – relief valve;
10 – pressure line to hydraulic control valve;
11 – steering worm;
12 – steering arm;
13 – power-assist piston rack;
14 – automatic differential lock system control valve;
15 – power-assist piston rack thrust block;
16 – feeler for setting steering arm to central position;
17 – spool valve of automatic differential lock system sender;
18 – steering wheel;
A – left-turn power chamber
B – right-turn power chamber


4
5
6
7
8
3
2
1
A
B
9
10
17
16
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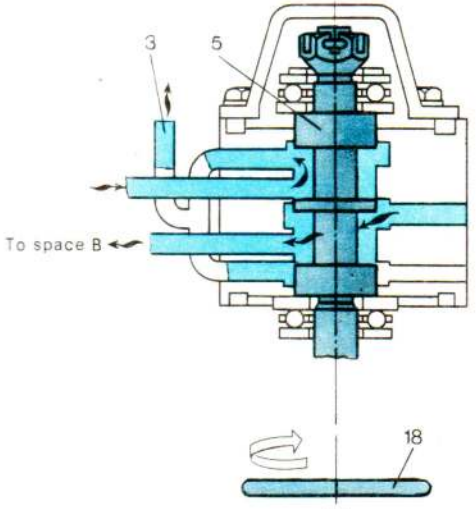
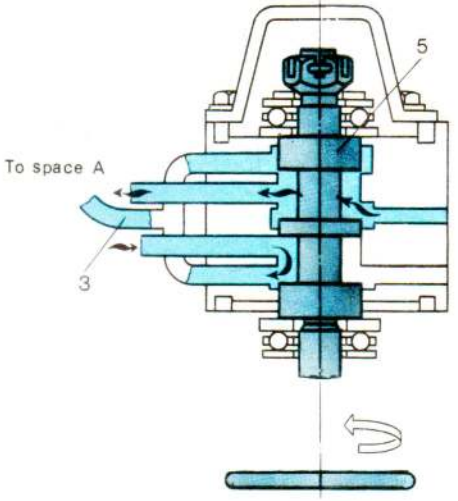
11
14
13
12
To differential lock clutch

(a)


3
5
To space B
18

(b)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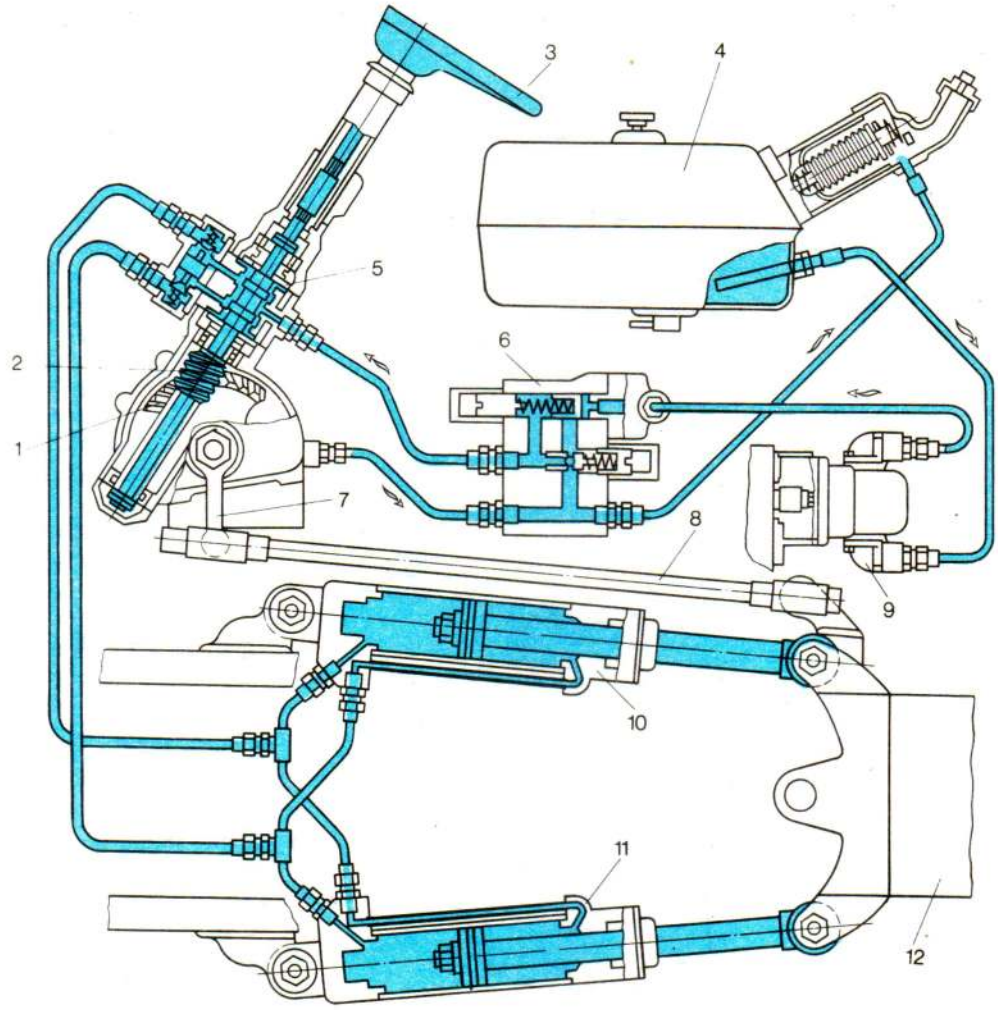
To space A
3

(c)



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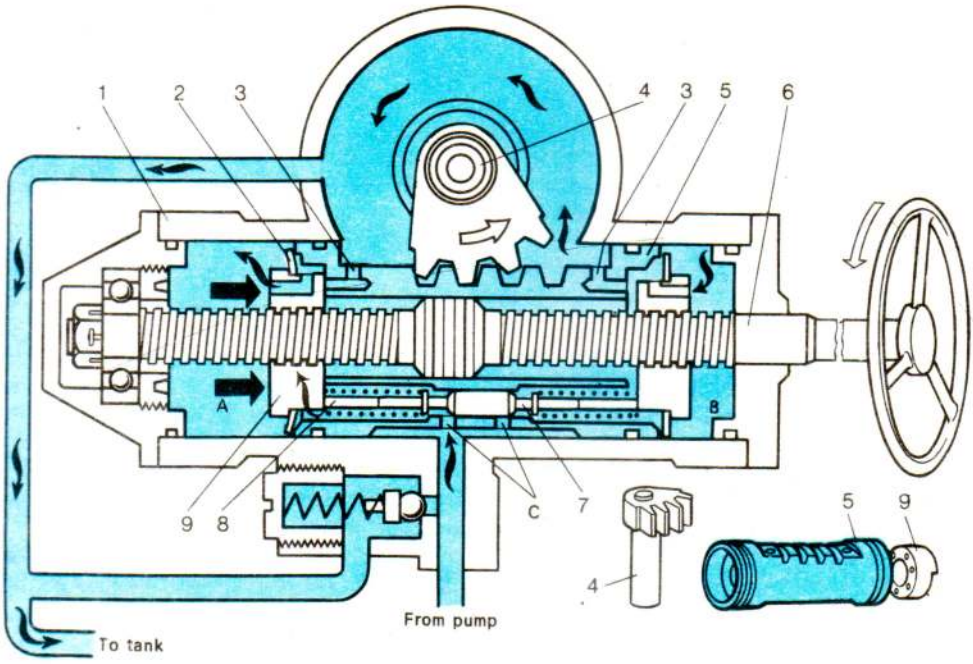
Schematic diagram of linkage-type power steering gear

1 – steering gear sector;
2 – steering worm;
3 – steering wheel;
4 – oil tank;
5 – hydraulic control valve;
6 – excess-flow-and-relief-valve unit;
7 – steering arm;
8 – steering gear connecting rod;
9 – oil pump;
10 and 11 – power-assist cylinders;
12 – rear half-frame

14.3. Steering System Troubles

The condition of the steering system has a profound effect not only on the performance of the tractor or automobile, but also on road and operation safety.

It is prohibited to operate a tractor or automobile suffering from the following steering troubles: hard steering, excessive play in the steering system, excessive wear of steering



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Screw-and-nut type of integral power steering gear (T-40M Model tractor)

1 – steering box;
2 – reaction ring;
3 – discharge passage;
4 – steering arm shaft;
5 – power-assist piston-rack;
6 – steering screw;
7 – spool valve;
8 – adjusting screw (stop);
9 – steering-gear nut;
A – left-turn power chamber;
B – right-turn power chamber;
C – inlet ports

system components, loose joints and fasteners, and damaged cotter pins.

Even a slight binding of the steering gear or linkage may result in an accident, for this condition is very tiring to the driver. Hard steering in conditions of heavy traffic and high running speeds is conducive to collisions and run-overs. If hard steering occurs just after the steering system has been worked on, the trouble is probably due to excessively tight adjustments in the steering gear or linkage. If it occurs at other times, hard steering could be due to excessive friction in the steering gear or linkage or at the ball joints, bent steering rods, or damaged steering worm bearings.

On a tractor or automobile with power steering, failure of the power steering gear will cause the steering system to change to mechanical steering. It will require greater steering effort to turn the steering wheel. When this happens, the power steering system and the pump should be checked and the cause of trouble revealed and corrected.

The steering linkage can be checked for binding by raising the front end of the tractor or automobile. Turn the steering wheel from left to right. If you feel any binding, disconnect the linkage from the steering arm. If this relieves the hard steering, the trouble is in the linkage. If hard steering is still a problem, the trouble is in the steering gear itself.

Damaged and badly worn components of the steering gear or linkage should be replaced, loose joints and fasteners tightened, and damaged or lacking cotter pins replaced.

Excessive play in the steering system shows up as a free movement of the steering wheel

without corresponding movement of the front wheels. A small amount of free play, or tilt, is desirable, because it makes steering easier. But when the play is excessive, it can make steering harder. Excessive play may be due to loose wheel bearings, steering-rod ball joints, steering-box fasteners, steering arm, and steering knuckle arms, and excessive backlash between the steering worm and roller (sector). These conditions are corrected in the same order as they are listed here.

ADJUSTING THE FRONT WHEEL BEARINGS. Normal axial play in the taper roller bearings of the front wheels is around 0.2 mm. The wheel bearings can be checked for looseness by raising the front end of the tractor or automobile. Then grasp the wheel at the top and bottom. If you can wobble the wheel, there is looseness in the wheel bearings or ball joints. Have someone apply the brakes as you again try to rock the wheel. If applying the brakes eliminates the free play, the wheel bearings are loose. If the play is more than 0.5 mm, the bearings should be adjusted.

Before making adjustment, clean the hub cap and remove it from the hub. Remove the cotter pin and tighten the adjusting nut until the wheel is tight on its spindle. Then back off the nut to make the nearest pin slot in the nut register with the pin hole in the spindle. With the bearings adjusted properly, the wheel should be easy to turn without any appreciable free play.

ADJUSTING THE WORM-AND-ROLLER TYPE OF MANUAL STEERING GEAR. If the steering wheel play is more than recommended by the manufacturer, the steering system should be adjusted.

First adjust the ball joints of the steering linkage and the front wheel bearings. If the steering wheel play still remains a problem, check the taper roller bearings of the steering worm (see Fig. 126) for looseness. To do this, disconnect steering gear connecting rod *15* from steering arm *16* and demesh steering worm *8* from the roller by turning the steering wheel either way. Grasp the steering wheel and move it up and down. If the movement of the steering shaft is noticeable, tighten the steering worm bearings by removing some of the shims placed under steering box bottom cover *1*. With the steering worm bearings adjusted properly, a force of 3 to 5 N (0.3 to 0.5 kgf) should be sufficient to turn the steering wheel.

Then set the roller at the center of the steering worm and check the backlash between them by rocking the steering arm. If the backlash is excessive, it should be adjusted.

The backlash between the roller and the steering worm should be adjusted as follows. Remove the steering gear, unscrew the lock nut of the adjusting screw, and remove tab washer *11*. Adjust the backlash by screwing in the adjusting screw so as to have the backlash at its minimum with the roller set at the center of the steering worm. Lock the adjusting screw with the tab washer and lock nut and mount the steering gear in place.

ADJUSTING THE WORM-AND-SECTOR TYPE OF POWER STEERING GEAR. If it proves impossible to eliminate the excessive steering wheel play by adjusting the ball joints of the steering linkage. it is then necessary to adjust the backlash between steering worm *6* (Fig. 128) and sector *8*. The outer end of the steering worm is supported by the ball bearing press-fitted in adjusting eccentric bushing 7. As the centers of the outer and inner surfaces of the bushing do not coincide, turning the bushing in its bore in the steering box will change the position of the steering worm relative to the sector. To make such an adjustment, remove the radiator shell, disconnect the steering knuckle tie rods from the steering arm, and loosen the two bolts that hold the flange of the adjusting bushing to the steering box. Insert a wrench in the slot in the bushing flange and turn the bushing clockwise (facing the front of the tractor) until there is no backlash between the steering worm and the sector with the steering arm in the central position. Then turn the flange of the bushing 4 to 6 mm counterclockwise and tighten its fastening bolts.

Finally, start the engine and check the steering gear for binding by turning the steering wheel all the way from left to right and back.

Review Questions

1. What are the main parts of the steering system?
2. What types of steering gear do you know?
3. How is the manual steering gear designed?
4. What are the component parts of the steering linkage?
5. What is the purpose of power steering?
6. Show in Fig. 129 the flow of oil to the automatic differential lock clutch.
7. How does the screw-and-nut type of steering gear operate?
8. List the typical steering system troubles.
9. What is the sequence of adjusting the steering wheel play?
10. What is used to adjust the backlash between the steering worm and the steering-gear sector?

Chapter 15

The Braking System

15.1. Types of Automotive Brakes

The purpose of the braking system is to slow down and stop the moving tractor or automobile, and also to hold it stationary in parking. A distinction is made between the service brake system, which serves to control the running speed of the vehicle and stop it smoothly, the parking brake system intended to hold the vehicle immovable when parked on an incline, and the auxiliary, or steering, brake system that is used on tractors to help the operator make sharp turns.

We have already discussed the steering brakes of tractors in connection with the design of the driving axles. Such brakes can be applied independently to one or the other axle shaft to brake the wheel or track nearest to the turning center. If necessary, the brakes can be used as service and parking brakes.

The braking system consists of one or several brake arrangements and brake controls.

THE BRAKE ARRANGEMENT serves to intentionally offer resistance to the movement of the tractor or automobile. Most common are friction brakes. These are essentially heat devices that change the kinetic energy of the moving vehicle into heat, by virtue of friction between a rotating component and a stationary component or components which are mechanically moved so that they come in contact with the rotating component. The stationary component or components are lined with a hard-wearing friction material, and when they are moved into contact with the rotating member, braking takes place. Friction brakes may be of drum, band, or disc type. In *the drum brake*, friction occurs on the inside cylindrical surface of a rotating drum; in *the band brake*, it occurs on the outside cylindrical surface of a rotating pulley, and in *the disc brake*, on the flat side surface of a rotating disc.

As regards their place of application, automotive brakes are divided into wheel, or hub, brakes and transmission brakes. The former act upon the wheel hubs, whereas the latter, upon one of the drive-line shafts. The wheel brakes belong to the service brake system. The transmission brakes find application in the parking brake system.

THE BRAKE CONTROLS are intended to transmit power to the actuating mechanisms of the brake arrangements and to control the operation of the brakes. As to their principle of operation, brake controls may be mechanical, pneumatic, hydraulic, or electric.

Mechanical brake controls find application on all tractors considered in this book. The parking brakes that are used on all automobiles and on some tractors also employ mechanical controls.

PARKING BRAKE. Some autombiles are equipped with a drum-type parking brake (Fig. 132). Brake anchor plate, or housing, 3 is mounted on the rear wall of the transmission case. Installed symmetrically on the anchor plate are two brake shoes 5. The shoes are arranged inside brake drum 7 that is held to the transmission main (output) shaft.

Riveted to the outside of each brake shoe is a facing of friction material. The facing is called the brake lining. The shoes are attached at one

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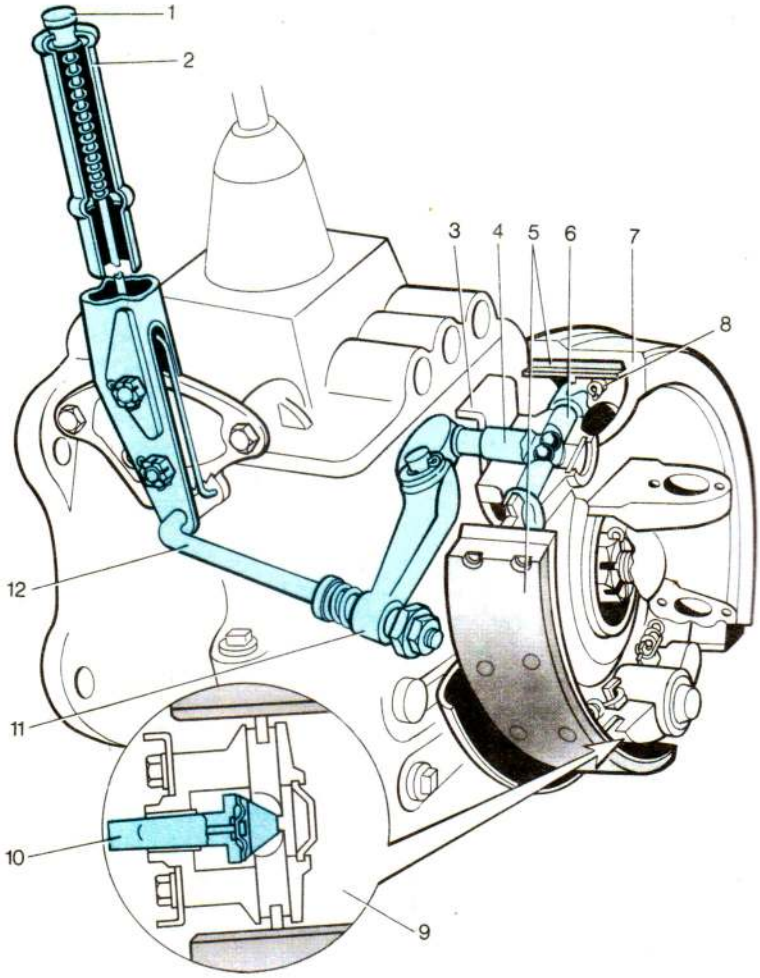
Drum-type parking brake

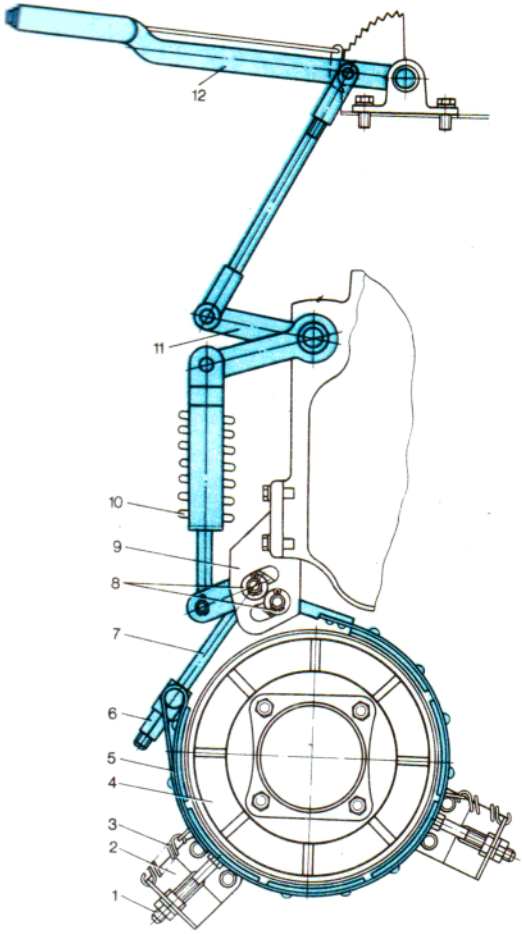
1 – brake lever latch button;
2 – brake lever;
3 – brake anchor plate (brake housing);
4 – brake expander rod;
5 – brake shoes;
6 – brake shoe actuating pin;
7 – brake drum;
8 – brake spring;
9 – brake adjuster;
10 – adjusting screw;
11 – actuating lever;
12 – brake rod



point to the brake anchor plate. The attachment is loose, so that the shoes can move around slightly. The lower ends of the brake shoes are pressed by springs against the conical head of adjusting screw *10* in the housing of brake adjuster *9*. The upper ends of the shoes are pressed by brake spring *8* against actuating pins *6* of the brake expander. The brake expander comprises rod *4* and two balls. The brake expander rod is linked with brake lever *2* by means of actuating lever *11* and brake rod *12*.

To apply the brake, the driver pulls back on lever *2*. This causes the lower end of the lever to swing forward and pull on the brake rod, which makes lever *11* pivot and push on brake expander rod *4*. The balls in the brake expander rod slide over the bevelled ends of brake shoe actuating pins *6*, thus forcing them apart, together with the upper ends of the brake shoes, to press the brake linings against the inside surface of the brake drum. This action brakes the drum and prevents rotation of the propeller shaft that is attached to the drum.

The parking brake can be latched in the applied position by means of a latch and quadrant. To release the brake, it is necessary to depress button *1* and move the brake lever



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Band-type parking brake (T-150K Model tractor)

1 – adjusting bolt;
2 – brake band anchor clip;
3 – brake band release spring;
4 – brake pulley;
5 – brake band;
6 – brake band adjusting nut;
7 – brake band clevis;
8 – pins;
9 – bracket;
10 – compensating spring;
11 – brake bell crank;
12 – brake lever

forward. This will pull back the brake expander rod, and the brake spring will draw together the upper ends of the brake shoes, thus releasing the brake drum. The necessary clearance between the brake linings and the drum is adjusted with the aid of adjusting screw *10*.

The band-type parking brake (Fig. 133) finds application on general-purpose wheeled tractors. With this brake, braking action is achieved by virtue of friction between steel brake band *5* with cast-iron linings and brake pulley *4* that is fixed to the rear end of the front drive shaft. The brake band encircles the pulley. One end of the band is fastened to bracket *9* bolted to the transfer case, and the other end is linked with brake lever *12* by a system of rod and levers. The lever is arranged in the driver's cab and can be latched in the applied position by means of a pawl and a toothed sector (quadrant).

The uniform clearance between the brake band and pulley is provided by brake band release springs *3* and adjusting bolts *1*. Pulling on brake lever *12* fully backwards causes the brake band to press tightly to the surface of the brake pulley and brake it securely. As soon as the brake lever is moved forward, the brake band release springs return the brake band to its initial position, thus releasing the brake pulley.

15.2. Hydraulic Brakes

The drum-type hydraulic wheel brakes (Fig. 134) find application on automobiles. The brake consists of two brake shoes *13* mounted on anchor (backing) plate *2*, wheel brake cylinder *3*, fulcrum pins *11*, and brake (adjusting) eccentrics *1*. The brake shoes are equipped with riveted-on friction linings. The front brake lining is pressed harder against the brake drum during braking, and so, to provide for uniform wear of both brake linings, the front brake lining is made longer than the rear one. The brake shoes are pulled together by brake spring *4*, also known as the retraction spring. The lower ends of the shoes are supported by eccentric washers *12* fitted on the fulcrum pins, while their upper ends rest against actuating pins, or links, *5* of the wheel brake cylinder pistons. The clearance between the brake shoes and drum is adjusted by means of brake cccentrics *1* that are installed in the brake anchor plate beneath the brake shoes.

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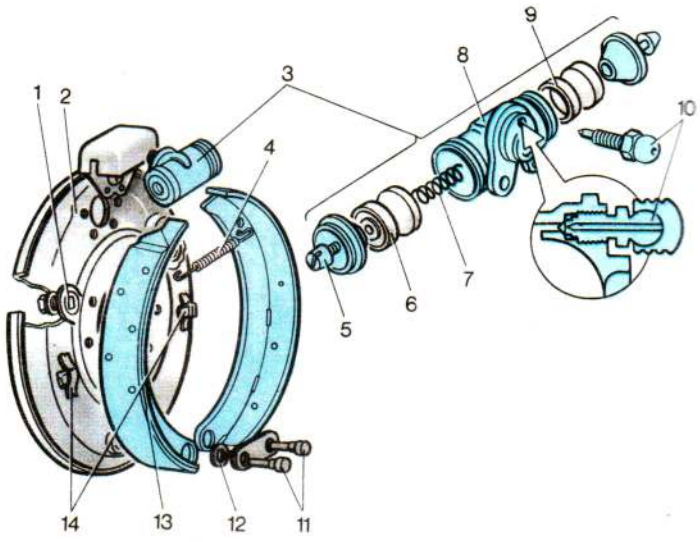
Drum-type hydraulic wheel brake (ГАЗ-53А Model truck)

1 – brake eccentric;
2 – brake anchor (backing) plate;
3 – wheel brake cylinder;
4 – brake spring;
5 – brake shoe actuating pin (link);
6 – wheel brake cylinder piston;
7 – expander spring;
8 – wheel brake cylinder body;
9 – piston cup;
10 – bleeder valve;
11 – brake shoe fulcrum pins;
12 – eccentric washer;
13 – brake shoe;
14 – brake shoe guide retainer anchor



THE WHEEL BRAKE CYLINDER consits of body *8* fixed to the brake anchor plate, two pistons *6* with cups *9*, and brake shoe actuating pins *5*. The piston cups are pressed against their respective pistons by expander spring *7*. To prevent the ingress of dust and dirt into the cylinder, both its ends are covered by protective rubber boots.

The wheel brake cylinder body has two passages. The lower passage receives the brake fluid from the brake master cylinder. The upper passage serves to bleed air from the braking system. The outlet hole of this passage is closed by bleeder valve *10* covered on the outside by a rubber cap. The brake fluid is carried by metal pipes, called brake lines, from the brake master cylinder to the various valves and then to the wheel brake cylinders. Brake lines usually pass on the underside of the automobile, where they are exposed to stones and other road damage. Because of this brake lines often are wrapped with a wire "armor" to protect them against damage. A short, flexible, rubberized-fabric brake hose (or "flex hose") is used to connect the stationary brake lines to the brake arrangements that move up and down and swing with each front wheel for steering. Only a single flexible hose is needed at the rear axle to take care of the up-and-down movement of the axle housing.

THE BRAKE MASTER CYLINDER (Fig. 135) is cast integral with fluid reservoir *1*. The master cylinder is fixed to the frame of the automobile. Its body *11* has a highly polished bore which contains piston *8* with rubber cup *12*, return spring *10*, and check valve *2*. The piston head is provided with bleeder holes that are closed by the leaves of plate valve *13* when the piston is pressed against its cup. The check valve is held to its seat by a weak spring. The master cylinder bore communicates with the fluid reservoir through breather port *9* and compensating port *5*. The reservoir is filled with the brake fluid through the filler hole in cover *3* that is closed by cap *4*. The entire braking system is always filled with the fluid. The brake fluid is a very special fluid that is little affected by high or low temperatures. It is not a type of engine oil. The fluid does not damage the metal or rubber parts in the braking system. Engine oil will damage the braking system. For this reason, only the brake fluid recommended by the automobile manufacturer should be put into the braking system.

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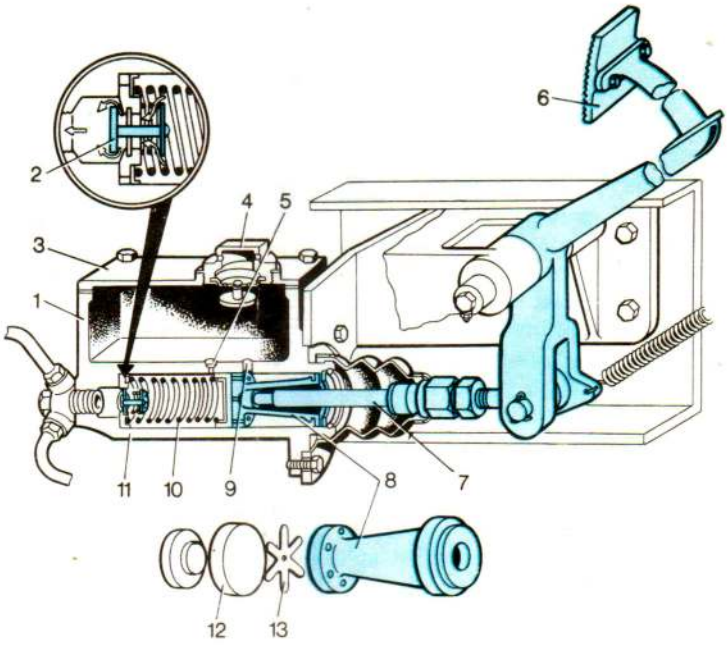
Brake master cylinder

1 - fluid reservoir;
2 - check valve;
3 - fluid reservoir cover;
4 - filler cap;
5 - compensating port;
6 - brake pedal;
7 - push rod;
8 - master cylinder piston;
9 - breather port;
10 - return spring;
11 - master cylinder body;
12 - rubber piston cup;
13 - plate valve

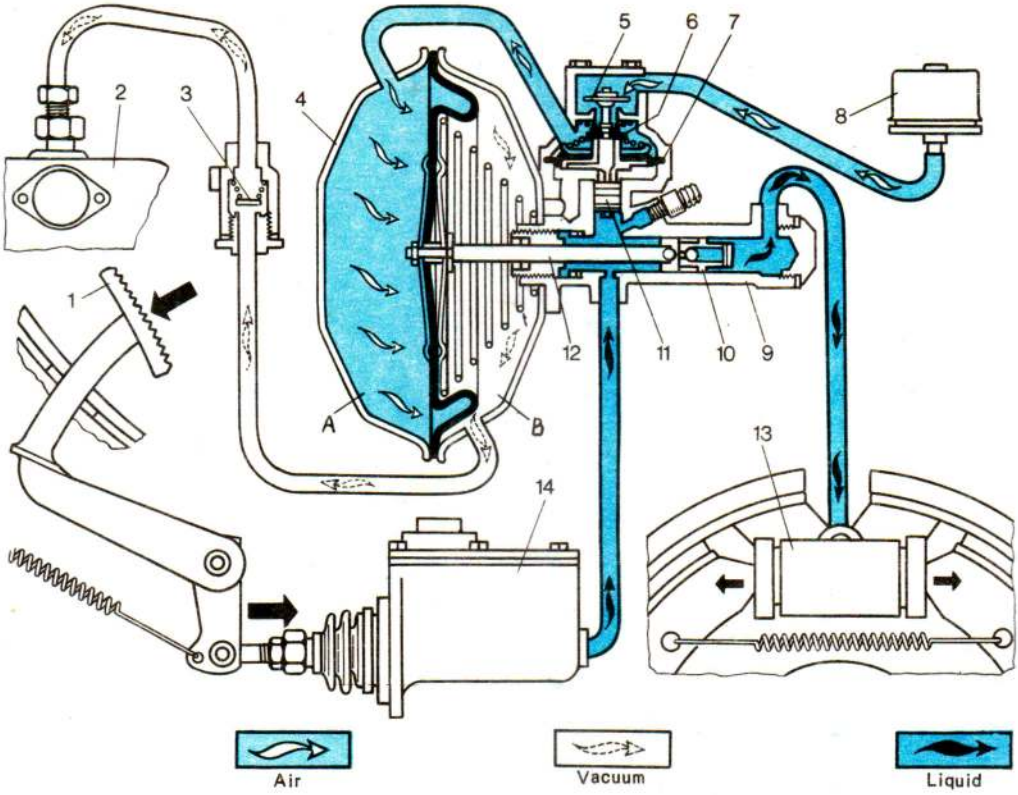


To slow down or stop the automobile, the driver depresses brake pedal *6*. When the brake pedal is depressed, push rod *7* forces master cylinder piston *8* forward. Initial movement causes the lip of piston cup *12* to cover compensating port *5*, which prevents escape of the brake fluid back to the reservoir. Continued movement builds up pressure, forcing the fluid into the brake lines leading to the wheel brake cylinders, which forces the brake cylinder pistons to move outward, pushing the brake shoes into contact with the wheel brake drums. The friction between the brake linings and the drums slows down or stops the rotation of the drums and the wheels.

When the driver releases the brake pedal, the brake spring tension on the brake shoes pulls the shoes away from the brake drums, pushing together the brake cylinder pistons. Also, return spring *10* in the brake master cylinder pushes its piston back toward the released position. All these actions draw the brake fluid out of the wheel brake cylinders and back into the brake master cylinder. However, some pressure is trapped in the brake lines and wheel brake cylinders by check valve *2* in the brake master cylinder. As the pressure drops in the brake lines, the check valve closes. It traps a slight pressure in the lines and in the wheel brake cylinders. This pressure causes the piston cups in the wheel brake cylinders to be held tight against the cylinder walls. Therefore, no air can leak into the wheel brake cylinders, and no brake fluid can leak out of them.

If the driver releases the brake pedal suddenly, the master cylinder piston moves faster than the brake fluid can follow. Therefore, a partial vacuum is momentarily created in the pressure chamber of the brake master cylinder. This vacuum is satisfied by the brake fluid flowing from the reservoir through breather port *9*, through the bleeder holes in the piston head uncovered by plate valve *13*, and past piston cup *12* to keep the pressure chamber filled. When the cup returns to its normal released position, excess brake fluid returns to the reservoir through uncovered compensating port *5*.

Most automobiles today are equipped with vacuum power brake systems which utilize the engine intake manifold vacuum and atmospheric pressure to provide power-assisted



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Illustrating the operation of a vacuum-and-hydraulic booster in a power brake system

1 – brake pedal;
2 – engine intake manifold;
3 – vacuum check valve;
4 – vacuum diaphragm chamber;
5 – air valve;
6 – vacuum valve;
7 – control valve diaphragm;
8 – air filter;
9 – hydraulic power cylinder;
10 – power piston;
11 – control valve piston;
12 – push rod;
13 – wheel brake cylinder;
14 – brake master cylinder;
A and B – vacuum diaphragm chamber spaces

application of vehicle brakes. One such system uses a vacuum-and-hydraulic booster inserted between the brake master cylinder and the wheel brake cylinders. The booster increases the brake fluid pressure in the system, when the brakes are applied, by 4,5 to 5 MPa, which corresponds to a brake pedal pressure of 650 to 700 N.

THE VACUUM-AND-HYDRAULIC BOOSTER (Fig. 136) consists of vacuum diaphragm chamber *4*, hydraulic power cylinder *9* with power piston *10*, and a control valve assembly. The vacuum diaphragm chamber comprises two cup-shaped shells stamped from sheet metal and a spring-loaded diaphragm sandwiched between the shells. The shells are held together by clips. Attached to the diaphragm by two plates and a nut is push rod *12* that is connected to power piston *10* of the hydraulic power cylinder. Inside the piston. there is a spring-loaded ball valve. The control valve assembly includes piston *11*. spring-loaded diaphragm *7*, air valve *5*, and vacuum valve *6*. Both valves are carried on a common rod.

The vacuum-and-hydraulic booster operates as follows. When the brake pedal is released. the air valve in the control valve assembly is closed, while the vacuum valve is open. The

spaces *A* and *B* of the vacuum diaphragm chamber communicate through the open vacuum valve, so that the diaphragm is balanced by equal pressure on both its sides.

When the driver depresses brake pedal *1*, brake master cylinder *14* sends the brake fluid through the open ball valve in power piston *10* to the wheel brake cylinders to actuate the brakes. As the pressure on the brake pedal is increased, control valve piston *11* and diaphragm *7* are pushed up. This action closes vacuum valve *6*, breaking communication between the spaces *A* and *B* of the vacuum diaphragm chamber, and opens air valve *5*. A vacuum is created in the space *B* because it is connected to the engine intake manifold by a vacuum line. The difference in pressure between the spaces *A* and *B* causes the diaphragm to deflect and push its rod together with power piston *10* to the right. This will cause the ball valve in the power piston to close, and the brake fluid pressure ahead of the piston will rise as a result of the additional pressure provided by the booster. The higher the pressure applied by the driver to the brake pedal, the higher the air pressure on the diaphragm of the booster and hence the fluid pressure in the wheel brake cylinders.

The vacuum line connecting the vacuum diaphragm chamber with the engine intake manifold incorporates vacuum check valve *3* designed to close automatically when the engine is stopped. The valve permits the vacuum remaining in the space *B* of the vacuum diaphragm chamber to be used for one or two applications of the brakes with vacuum-assist after the engine has stopped. In the case of vacuum failure, the brakes can be applied in the conventional manner, but since the vacuum-assist is not available, the brake pedal pressure will be higher.

15.3. Pneumatic (Air) Brakes

Some tractors and automobiles are equipped with pneumatic (air) brake systems. Such a system consists of wheel brake arrangements (or simply brakes) and pneumatic brake controls. The pneumatic brake systems used on trucks and general-purpose wheeled tractors are similar in design.

WHEEL BRAKE (Fig. 137). The wheel brake drum of a general-purpose wheeled tractor is fixed to the flange of the wheel-hub reduction gear housing. The brake arrangement includes brake anchor plate *2* rigidly held to the flange of the axle drive housing. The anchor plate carries two eccentric pins *1* that support the front ends of brake shoes *11*. The other ends of the brake shoes are pressed by brake spring *12* against brake cam *10* whose shaft is free to turn in bushings pressed in bracket *9* that is bolted to the brake anchor plate. Splined to the end of the brake camshaft is brake adjuster lever *7* connected by push rod *6* to diaphragm *4* of brake chamber *5*. The brake chamber is rigidly attached to the brake anchor plate by brackets.

The necessary clearance between the brake shoes and drum is adjusted by means of eccentric brake shoe fulcrum pins *1*, which are fixed in position by nuts, and a brake adjuster accommodated in lever *7*.

The brake adjuster consists of worm *8* and worm wheel *14*. Turning the worm by the square end of its shaft causes the worm wheel to turn with the brake camshaft, thus changing the position of the brake cam relative to the ends of the brake shoes. This causes the clearance between the brake shoes and the drum to change. Lock *13* prevents unintentional turning of the worm.

PNEUMATIC SYSTEM AND CONTROLS. Figure 138 illustrates the arrangement of the pneumatic brake system and controls of an automobile. In this case, the system is used to actuate and control both the wheel brakes and windshield wipers. Brake reservoirs *3* serve to store compressed air. When braking, compressed air is delivered from the reservoirs to brake chambers *4* and *9* to apply the brakes and slow down or stop the vehicle. On wheeled tractors compressed air provided by the system is also used to operate the clutch, inflate tires, fill the fuel tanks, etc.

BRAKE CHAMBER *5* (Fig. 137) actuates the wheel brake arrangement at the expense of the energy of compressed air. SYndwiched between

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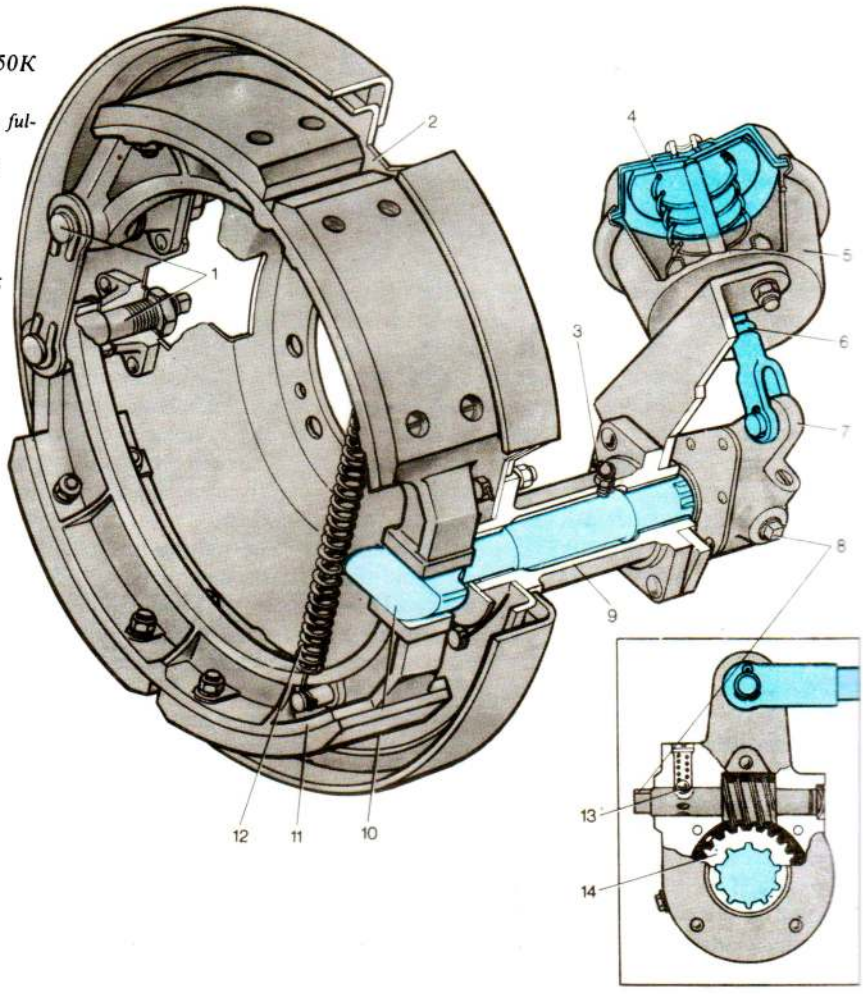
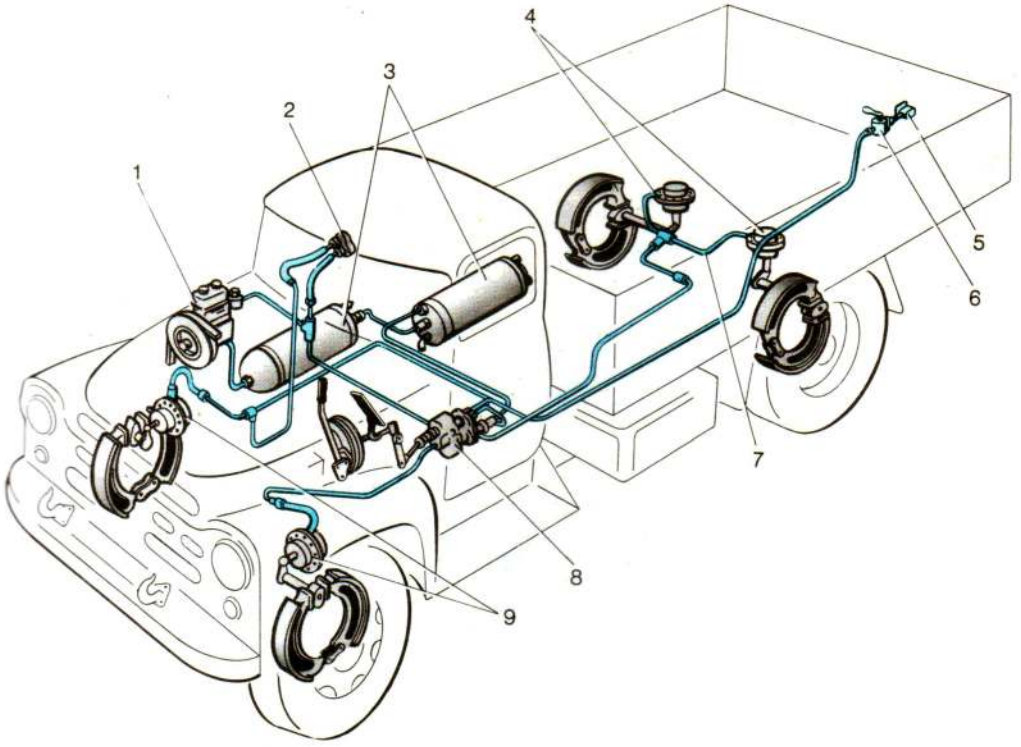
Wheel brake (T-150K Model tractor)

1 – eccentric brake shoe fulcrum pins;
2 – brake anchor plate;
3 – grease fitting;
4 – diaphragm;
5 – brake chamber;
6 – push rod;
7 – brake adjuster lever;
8 – worm;
9 – bracket;
10 – brake cam;
11 – brake shoe;
12 – brake spring;
13 – ball-type lock;
14 – worm wheel



the body and cover of the brake chamber is rubberized-fabric diaphragm *4* with a central metal disc. In the released position, the diaphragm is pressed against the brake chamber cover by a spring. Tightly fitted in the central hole in the diaphragm disc is push rod *6* with a fork screwed on its other end. The fork is locked in place on the push rod by a jam nut. Mounted on the brake chamber cover is a hose fitting to connect the chamber to the brake valve which controls the delivery of compressed air from the brake reservoirs to the brake chambers for braking.

When the driver depresses the brake pedal, compressed air is fed into the space between the brake chamber cover and the diaphragm, which causes the diaphragm to deflect and push its disc together with the push rod to the bottom of the brake chamber. The push rod forces lever 7 which is connected to its fork, to turn together with the brake camshaft and cam *10*. As the brake cam turns, it moves apart the brake shoes, pushing them into contact with the brake drum, and the wheel is thus stopped. As soon as the brake pedal is released, the brake shoes are pulled from the drum by brake spring *12*



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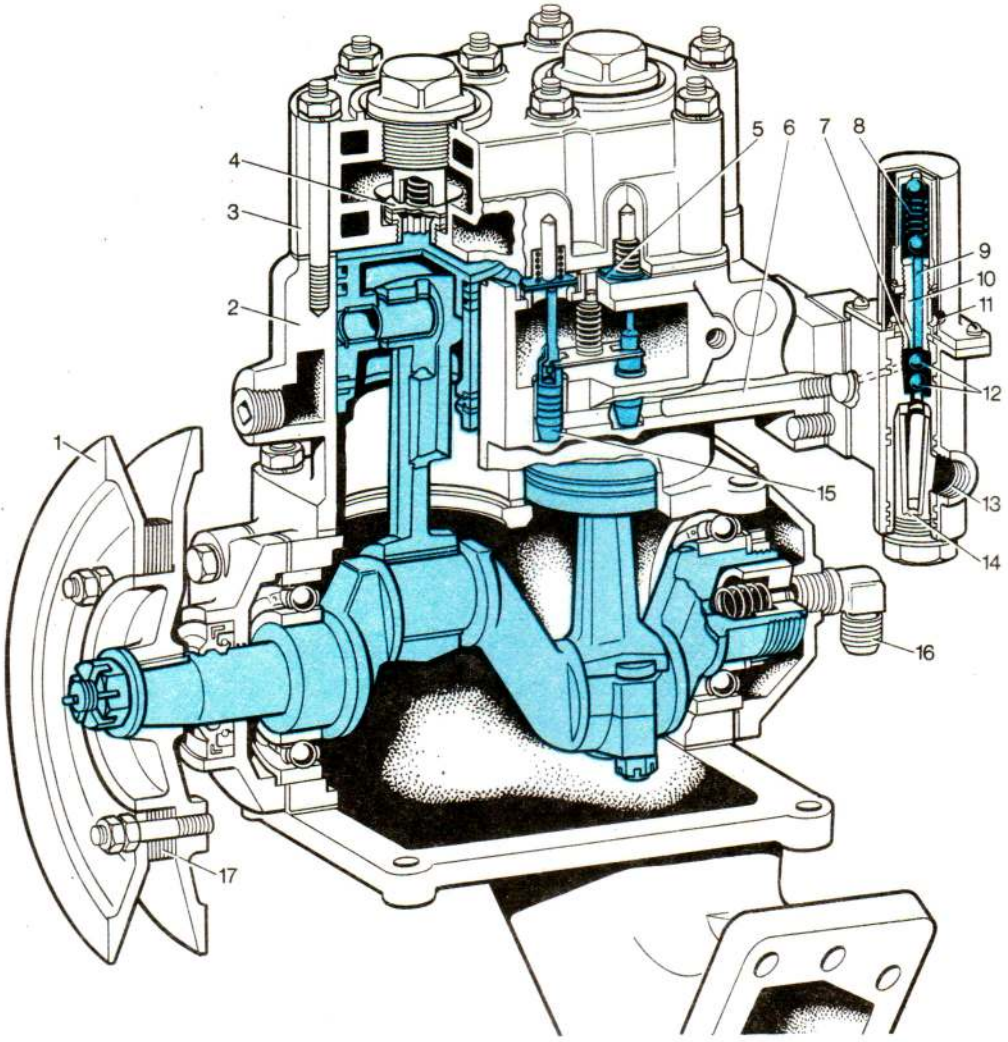
Pneumatic brake system of an automobile

1 – brake (air) compressor;
2 – pressure gauge;
3 – brake reservoirs;
4 – rear wheel brake chambers;
5 – coupling head;
6 – disconnecting valve;
7 – air hose;
8 – brake valve;
9 – front wheel brake chambers

THE BRAKE (AIR) COMPRESSOR (Fig. 139) is a reciprocating double-cylinder type machine whose purpose is to pump air into the brake reservoirs. It consists of a crankcase, cylinder block *2*, cylinder head *3*, connecting-rod-and-piston assemblies, a crankshaft, a valve arrangement, and a compression release device. Fixed by a key and a nut to the front end of the compressor crankshaft is drive pulley *1* which is driven from the engine crankshaft pulley by a V-belt drive. The valve arrangement comprises two delivery valves *4* and two intake valves *5*, and their associated springs.

As the piston in one of the compressor cylinders moves down, a depression is produced in the cylinder, which causes its intake valve *5* to open to let atmospheric air enter the cylinder through an air filter. As the piston moves up, the intake valve closes, and the air trapped in the cylinder is compressed. As soon as the air pressure in the cylinder becomes equal to the spring pressure on delivery valve *4*, the valve is lifted off its seat, and compressed air enters the cylinder head and thence the brake reservoirs.

The compression release device is housed in the cylinder block and controlled by pressure regulator *7*. The device consists of two plungers *15* with rods and a yoke. When the air pressure in the pneumatic system reaches 0.75 MPa, the pressure regulator lets compressed air in compression release passage *6*, which causes both compression release plungers to lift and



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Brake (air) compressor

1 – drive pulley;
2 – cylinder block;
3 – cylinder head;
4 – delivery valve;
5 – intake valve;
6 – compression release passage;
7 – pressure regulator;
8 – adjusting cap;
9 – rod;
10 – nipple;
11 – air hole;
12 – ball valve assembly;
13 – compressed air inlet from brake reservoirs;
14 – air filter;
15 – compression release plunger;
16 – oil line inlet fitting;
17 – adjusting shims

open the intake valves in both compressor cylinders. In this case, air freely flows from one cylinder to the other, and so no compressed air is delivered by the compressor. When the air pressure in the system drops to 0.6 MPa, the intake valve springs force the valves against their seats, lowering the compression release plungers, so that the compressor is operative again. The compressor continues to deliver compressed air until the air pressure in the system reaches 0.75 MPa once more. The

rubbing components of the compressor are lubricated with oil supplied from the main oil gallery of the engine via an oil line connected to fitting *16* whence the oil is directed to the crankshaft main and crankpin bearings. The cylinder block and head of the compressor get heated to a high temperature during operation. Therefore, they are cooled with water coming into their cooling jacket from the cooling system of the engine.

PRESSURE REGULATOR *7* automatically maintains the specified air pressure in the pneumatic system. It consists of a housing and ball valve assembly *12*. When the air pressure in the system is below 0.6 MPa, both ball valves are down. The lower valve is pressed against its seat and thus closes the compressed air inlet from the brake reservoirs, while the upper valve is off its seat, so that atmospheric air can enter compression release passage *6* through air hole *11* in the pressure regulator cover and an inclined air passage in nipple *10*. In this position, the brake compressor operates normally, delivering compressed air to the brake reservoirs.

When the air pressure in the system reaches 0.75 MPa, the ball valves of the pressure regulator are lifted. The upper valve is pushed tightly to its seat to break communication between the compression release passage and the atmosphere, while the lower valve opens to let compressed air from the brake reservoirs in the compression release passage, which causes the compression release plungers to lift, thus disabling the intake valves in the compressor cylinders.

The maximum air pressure in the pneumatic system is adjusted by turning adjusting cap *8* to change the spring pressure on the pressure regulator valves. The minimum pressure is adjusted by changing the thickness of the pack of adjusting shims placed under nipple *10*.

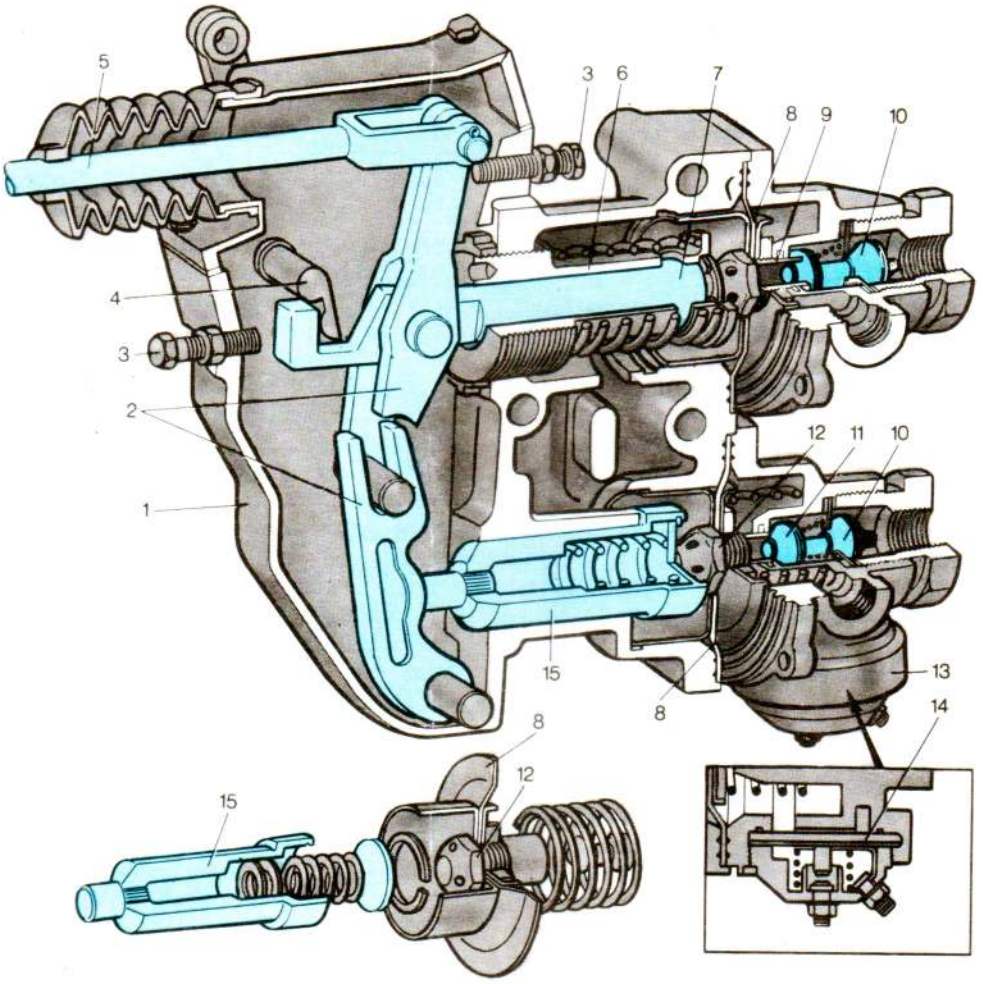
THE BRAKE RESERVOIRS (cylindrical metal tanks) are necessary to store compressed air. Their capacity is sufficient for eight to ten applications of the brakes. The reservoirs are fixed to the frame girders. Each reservoir is equipped with a condensate drain cock. The right-hand reservoir also has a service air valve.

To prevent the air pressure in the pneumatic system rising too high in case the pressure regulator or compression release device should fail, one of the brake reservoirs is provided with a safety valve set to open at a pressure of 0.95 MPa.

THE BRAKE VALVE (Fig. 140) is a combination valve designed to control the operation of the wheel brakes of the tractor and its trailer (if used). The brake valve is mounted on the frame girder and comprises two individual sections housed in a common body. The lower section serves to control the brakes of the tractor, while the upper one, those of the trailer.

Each brake valve section is provided with a separate cover and houses flexible rubberized-fabric diaphragm *8* sandwiched between the brake valve body and the cover and loaded by a spring. In the center of the diaphragm, there is a release valve seat. Each brake valve section cover accommodates delivery valve *10* and release valve *11* that are carried on a common rod and loaded by a common spring. The diaphragms can be acted upon by spring-loaded rods *7* and *15* accommodated in the brake valve body.

The rods are operated by articulated lever *2* that is hinged to brake rod *5* linked with the brake pedal. The articulated lever is contained in housing *1*, which is attached to the brake valve body, and its travel is limited by adjusting bolt *3* screwed in the walls of the housing. Depressing the brake pedal moves brake rod *5* to the left, which causes the upper portion of articulated lever *2* to pivot on its lower end and pull on rod *7* of the upper brake valve section to actuate the wheel brakes of the trailer. As soon as the upper portion of the articulated lever comes to rest against the left-hand adjusting bolt *3*, it starts to pivot on rod *7*, moving the top end of the lower portion of the articulated lever to the right. This causes the lower portion of the articulated lever to pivot on its bottom pin and push on rod *15* of the lower brake valve section to actuate the wheel brakes of the tractor. Thus, the articulated lever permits the wheel brakes of the trailer to be applied somewhat earlier than those of the tractor, which excludes the possibility of the trailer



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Brake valve

1 – articulated lever housing;
2 – articulated lever;
3 – adjusting bolt;
4 – cam;
5 – brake rod;
6 – guide;
7 – brake valve trailer section rod;
8 – diaphragm;
9 and 12 – release valve seats;
10 – delivery valve;
11 – release valve;
13 – stop light switch;
14 – stop light switch diaphragm;
15 – brake valve tractor section rod

running into the tractor during braking.

In the released position (Fig. 141*a*), delivery valve *3* of the upper (trailer) brake valve section is open, so that compressed air flows from tractor brake reservoir *8* and through distribution valve *5* to charge brake reservoir *6* of the trailer. The delivery valve of the lower (tractor) section of the brake valve is closed. whereas its release valve is open and lets the wheel brake chambers of the tractor communicate with the atmosphere.

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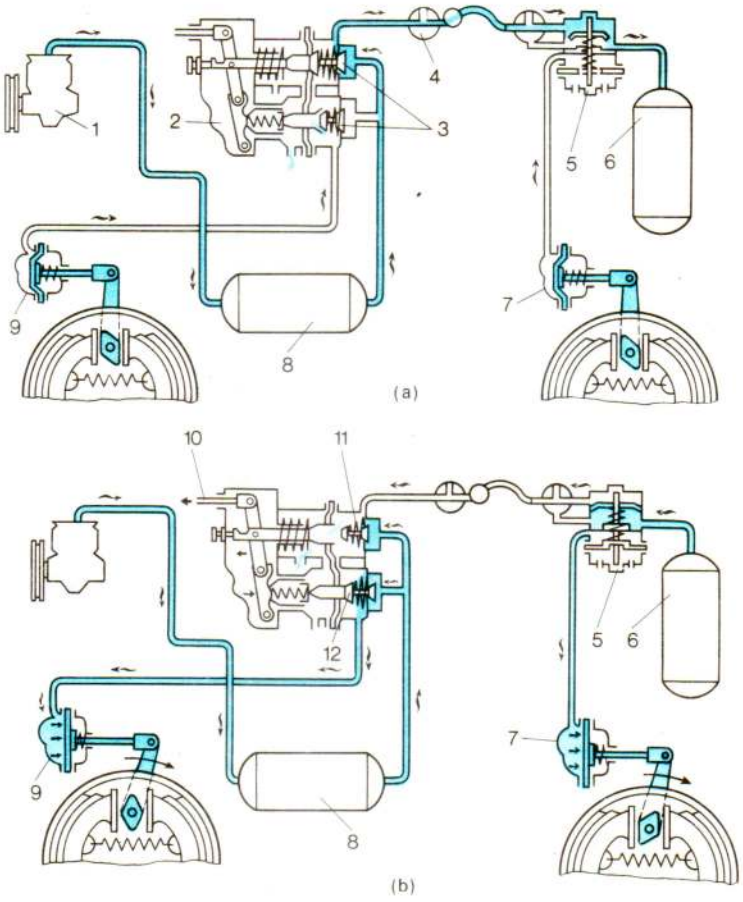
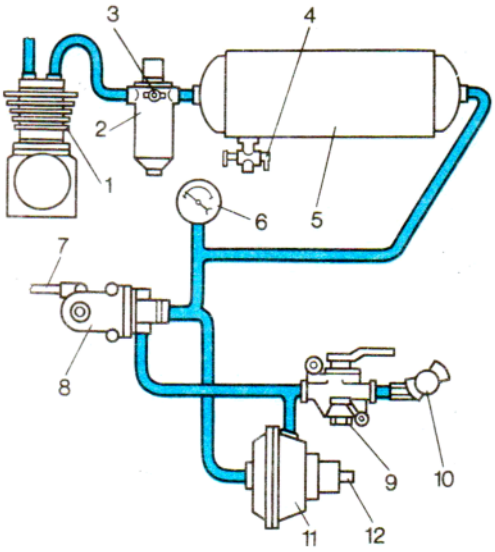
...ustrating the operation ...air brakes

... released position;
... applied position;
... brake compressor;
... brake valve;
... delivery valve;
... disconnecting valve;
... distribution valve;
... trailer brake reservoir;
... trailer wheel brake chamber;
... tractor brake reservoir;
... tractor wheel brake chamber;
... brake rod;
... delivery valve spring;
... release valve



When the driver depresses the brake pedal, brake rod *10* (Fig. 141 *b*) moves to the left together with the upper portion of the articulated lever and the rod of the upper brake valve section. This releases the diaphragm in this section. The diaphragm spring forces the diaphragm to deflect to the left, carrying the seat of the release valve of the upper brake valve section away from its valve, thus opening the release valve and, at the same time, allowing spring *11* to press the delivery valve tightly to its seat (i. e., to close the delivery valve). Compressed air escapes from the top chamber of distribution valve *5* through the open release valve, which causes the distribution valve to break communication between the brake valve and brake reservoir *6* of the trailer and direct compressed air from the reservoir to wheel brake chambers *7* to slow down or stop the trailer. Thus, the wheel brakes of the trailer are applied whenever the air pressure in the air line between the tractor and the trailer drops below a predetermined level. If the air line leading from the tractor to the trailer should be damaged, or if the trailer should accidentally break loose from the tractor, the trailer will be braked automatically at the expense of the compressed air stored in the brake reservoir of the trailer.

Depressing further the brake pedal will cause the lower portion of the articulated lever to move the rod of the lower section of the brake valve to the right. The rod will force the diaphragm in this section to deflect to the right,



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Air brake system of MT3-80 Model tractor

1 – brake compressor;
2 – pressure regulator;
3 – service air valve;
4 – condensate drain cock;
5 – brake reservoir;
6 – pressure gauge;
7 – brake rod;
8 – brake valve;
9 – disconnecting valve;
10 – coupling head;
11 – pneumatic-to-hydraulic converter;
12 – push rod

push the seat of the release valve of the lower brake valve section tightly against its valve, thus closing it, and then open the delivery valve. Now, compressed air will flow from brake reservoir *8* of the tractor and through the open delivery valve to wheel brake chambers *9* to slow down or stop the tractor.

The pressure in the wheel brake chambers of both the tractor and trailer rises in proportion to the brake pedal pressure.

To brake the trailer for parking, provision is made in the braking system for a mechanical connection between the transmission brake linkage and the brake valve of the tractor. Pulling back on the transmission (parking) brake lever will cause the shaft that carries cam *4* (see Fig. 140) to turn and pull on the rod of the upper brake valve section, and the wheel brakes of the trailer will thus be applied.

THE AIR BRAKE SYSTEM OF ROW-CROP TRACTORS (Fig. 142) differs from the system considered above in that it is equipped with a single brake reservoir, its brake compressor has only one cylinder, and its brake valve controls the wheel brakes of the trailer alone (if any). Also, brake valve *8* and pressure regulator *2* differ in design from their counterparts considered above. The pneumatic system of these tractors includes pneumatic-to-hydraulic converter *11* which enables the tractor to be used for towing trailers equipped with hydraulic brakes. The converter is essentially an ordinary wheel brake chamber whose push rod *12* actuates the master cylinder piston of the trailer hydraulic brake system. When the tractor is teamed with a trailer having air brakes, the push rod of the converter is covered with a cap, and the air hose of the trailer is connected to the tractor pneumatic system by means of coupling head *10*.

THE COUPLING HEAD is part of a breakaway air-hose connection and consists of a body, a spring-loaded check valve, and a cover. If the trailer should break loose from the tractor on the run, the air hose of the trailer will be pulled out of the coupling head, and the check valve in the head will prevent the escape of compressed air from the pneumatic system of the tractor.

Pneumatic systems of tractors and automobiles also include disconnecting valves *9*, service air valves *3*, pressure gauges *6*, windshield wiper motors, and air lines.

THE DISCONNECTING VALVE, as its name implies, serves to disconnect the air line of the trailer from the pneumatic system of the tractor (or automobile) whenever the tractor is used without the trailer. The valve consists of a body, a conical plug, a spring, and a handle. When the handle is placed along the valve body, the valve is open. To close the valve, the handle should be placed at right angle to the valve body.

PRESSURE GAUGE *6* is mounted on the instrument panel of the vehicle. It serves the purpose of checking the air pressure in the pneumatic system and is provided with two scales. The upper scale reads the pressure in the brake reservoirs *5*, while the lower, that in the brake valve during braking. If there is not

enough compressed air in the brake reservoirs, it is prohibited to operate the tractor (or automobile). In this case, the pointer of the pressure gauge reads zero with the brake pedal released.

15.4. Braking System Troubles

Road safety largely depends both on the condition of the vehicle brakes and on the driver's skill in applying them. When you are operating a tractor or automobile, do not apply the brakes too frequently or too hard, for this accelerates wear of the brake linings and brake drums.

The various braking system troubles result in poor braking action, vehicle pulling to one side during braking, and failure of the brakes to release.

Poor braking action may be caused by loss of brake fluid or compressed air due to leaky brake lines or flexible hoses, air in the hydraulic brake system, brake shoes out of adjustment, grease or brake fluid on the shoes, or excessively worn brake shoes or drums.

The points of leakage in the hydraulic brake system usually are easy to find because they will be covered with dirt that has stuck to the fluid as it leaked out. A leaky condition of the air brake system will cause the air pressure to drop when the engine is stopped. (Note. Air pressure dropping while the engine is running points to a faulty brake compressor). Leaky spots in the air brake system can be detected by listening for the hissing of escaping air, or by applying soapy water to brake line connections where air leaks are most likely to occur. If there is a leak, air bubbles will show.

Air trapped in the hydraulic brake system will cause the brake pedal to go to the floorboard, or it will make the pedal soft or spongy. To remove air from the system, the latter must be "bled". This procedure requires two persons to perform. The sequence of operations is as follows. Add brake fluid to make its level in the fluid reservoir of the brake master cylinder stand 15 to 20 mm below the filler hole. Remove the rubber cap from the bleeder valve on the right rear wheel cylinder and fit a rubber hose 350 to 400 mm long on the valve head. Immerse the other end of the hose in a half-liter glass jar filled half its capacity with brake fluid. Unscrew the bleeder valve one half to three fourths of a turn. Tell your assistant to pump the brake pedal several times. The pedal should be depressed quickly and released slowly. Continue pumping the pedal until air bubbles stop escaping from the hose in the jar. Add brake fluid to the reservoir every five or six pumpings of the pedal to keep the reservoir filled and prevent air entering the system through the master cylinder. As soon as air bubbles cease escaping from the hose, tighten the bleeder valve securely with the brake pedal fully depressed.

Repeat the procedure for all the other wheels in the following sequence: front right, front left, and then rear left.

With the system free from air and the brake arrangements adjusted properly, the brake pedal must go no more than half the distance to the floorboard.

Oil can get onto the brake shoes from faulty axle shaft seals. Should this prove to be the case, the seals must be replaced and the shoes and drums washed with gasoline. After washing, the brake linings must be rasped or wire-brushed.

Worn brake linings should be replaced and then the clearance between the new linings and the drum adjusted.

If the air brake system loses air, the cause must be revealed and the trouble corrected.

A vehicle pulling to one side during braking may cause skidding accidents. This trouble means that more braking friction is being applied to one brake drum than the other. The problem could be caused by grease or brake fluid on brake linings, brake shoes out of adjustment, sticking brake camshafts or wheel brake cylinder pistons, or restricted brake lines or hoses.

Brake linings with grease or brake fluid on them must be washed with gasoline and then rasped or wire-brushed. Improper brake shoe adjustment should be corrected. Stuck brake camshafts should be removed, cleaned,

lubricated, and installed in place. Wheel brake cylinders with stuck pistons must be replaced. Restricted brake lines or hoses must be cleared with compressed air.

Failure of the brakes to release may be due to sticking components in the wheel brake arrangements. This may be caused by brake linings broken loose from their shoes, brake shoes frozen to the drums, broken brake springs, clogged air vent and compensating holes in the brake master cylinder, or stuck pistons in the wheel brake cylinders.

Brake shoes frozen to the drums can be freed by heating the drums to melt the ice. Broken components should be replaced. Clogged holes in the master cylinder should be cleared with a piece of copper wire. Wheel cylinders with stuck pistons must be replaced.

Failure of parking brakes to hold usually is caused by excessive clearance between the brake shoes or band and the drum or pulley. This trouble is corrected by properly adjusting the clearance.

Review Questions

1. What types of friction brakes do you know?
2. What are the types of brake controls used on automobiles and tractors?
3. Where is friction advantageous and where is it not?
4. What is the difference between the parking brakes of tractors and automobiles?
5. What is the difference between the hydraulic and pneumatic wheel brake arrangements?
6. How is the brake master cylinder constructed?
7. What is the purpose of the vacuum-hydraulic booster?
8. What is the brake fluid?
9. List the component parts of the air brake system.
10. How does the air pressure regulator operate?
11. Referring to Fig. 141*b*, explain what happens when the brake pedal is depressed.
12. List the most common troubles of the braking system.

Chapter 16

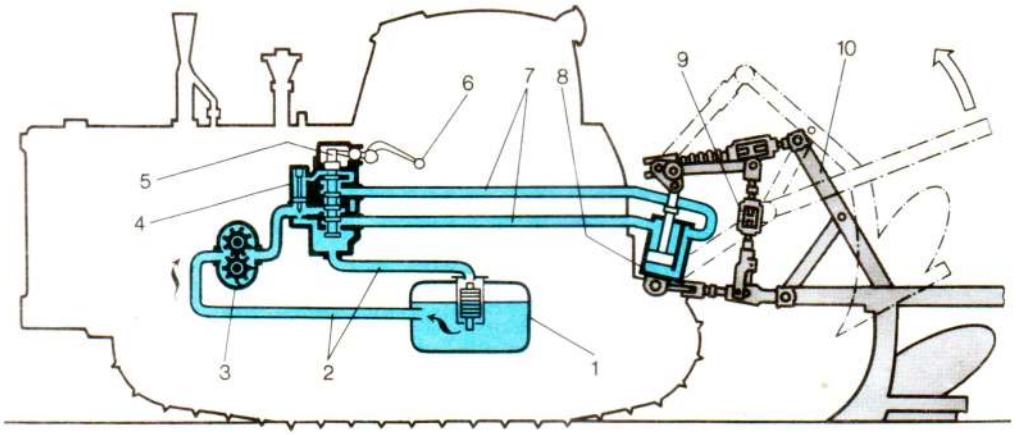
Working Attachments of Tractors

Working attachments are necessary to utilize the useful power of the tractor, teamed with various farm machines or implements, for the many and time-consuming tasks carried out on the land. The attachments include a hydraulic lift (implement-attaching) linkage system, a drawbar hitch (coupling), a draft hook, a power takeoff (PTO) shaft, and a belt pulley.

16.1. General Design of Hydraulic Lift Linkage System

Modern tractors manufactured in this country are equipped with a hydraulic lift linkage system that allows fully mounted, semi-mounted, and draft implements to be hitched to the tractor. The system is controlled by the tractor driver from his driving seat in the tractor cab. It includes a hitch linkage and a hydraulic lift mechanism. The hitch linkage serves to attach agricultural implements to the tractor. It consists of several links, rods, and arms, usually installed at the rear of the tractor.

The purpose of the tractor hydraulic system is to lift and lower the implements attached to the tractor. The system (Fig. 143) includes oil tank *1*, oil (hydraulic) pump *3*, hydraulic control (selector) valve *4*, and power (hydraulic ram) cylinders *8*. The hydraulic system units are situated in different locations on the tractor, and are interconnected by rigid and flexible oil (hydraulic) lines. The oil tank is connected by a metal oil line (pipe or tube) to the suction side (chamber) of the oil pump, whose discharge side is, in turn, connected to the hydraulic control valve. Hydraulic control levers *6* are arranged in front of the driver in his cab. The triple-spool hydraulic control valve makes the system universal, allowing front-, mid-, and rear-mounted implements to be controlled individually, by means of power cylinders connected to the discharge chamber of the valve. The exhaust chamber of the control valve



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Schematic diagram of a tractor hydraulic system

1 – oil tank;
2 – low-pressure oil (hydraulic) lines;
3 – oil (hydraulic) pump;
4 – hydraulic control (selector) valve;
5 – control (valve) spool;
6 – hydraulic control lever;
7 – high-pressure oil lines;
8 – power cylinder;
9 – hitch linkage;
10 – mounted implement

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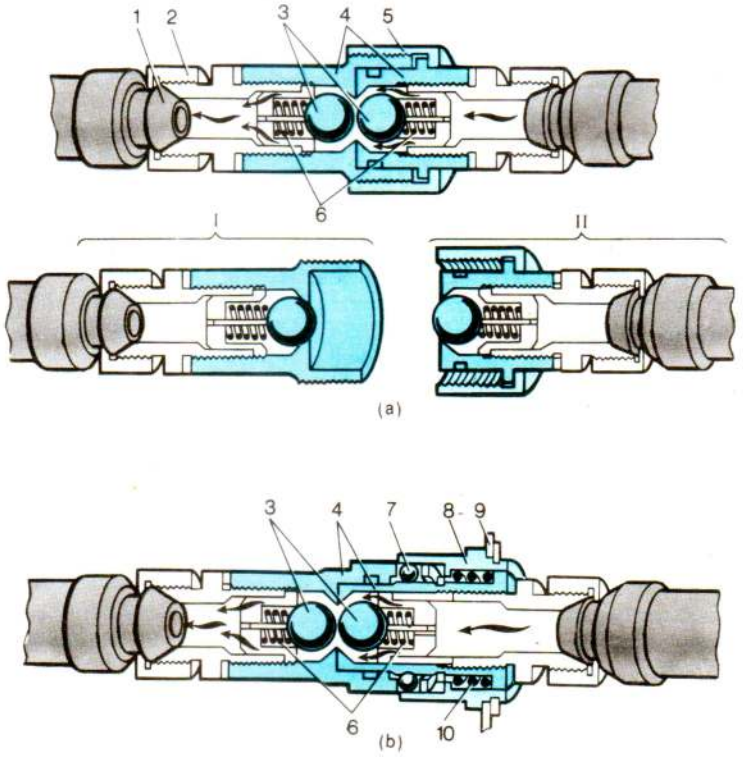
Hydraulic hose connections

(a) rigid type;
(b) breakaway type;
1 – nipple;
2 and 5 – swivel nuts;
3 – shutoff ball valves;
4 – female and male connectors;
6 – shutoff valve spring;
7 – lock balls;
8 – bushing;
9 – bracket;
10 – spring;
11 – female connector assembly
12 – male connector assembly



is connected to the oil tank through an oil filter.

The hydraulic system relies for its operation on the pressure of oil forced by the oil pump into the power cylinder. During operation, the pump delivers oil, under high pressure, to the hydraulic control valve. Depending on the position of the hydraulic control lever, the oil is directed by one of oil lines *7* to one or the other power chamber (space) of the power cylinder to raise or lower the implement attached to the cylinder, or else is returned to the oil tank.

The hydraulic system of row-crop tractors includes, in addition to the above units, also a hydraulic or mechanical traction booster that makes it possible to increase the adhesion weight of the tractor at the expense of the weight of the attached implement and thus improve its traction.

As mentioned earlier, the various units of the hydraulic system are interconnected by oil lines. Low-pressure oil lines that connect the oil tank to the oil pump and the hydraulic control valve use steel pipes or tubes. High-pressure oil lines connecting the oil pump to the hydraulic control valve and the valve to the power cylinders employ both steel pipes or tubes and flexible tubes or hoses. Hydraulic hose constructions are numerous. Generally, the hoses are made up of a rubber inner tube reinforced with one or several braids of fabric cord and one braid of steel wire, and covered with a rubber cover.

To facilitate the mounting and demounting of power cylinders, the latter are connected into the hydraulic system by means of separate lengths of hose coupled by special connections (Fig. 144) that are equipped with shut-off ball valves. The connections may be of rigid type (Fig. 144*a*) or of breakaway type (Fig. 144*b*). The former type is used to connect power cylinders mounted on the tractor itself, whereas the latter is used for remote cylinders mounted on a trailer-type machine or a draft implement. Where such connections are employed, the hose ends are equipped with adapters comprising taper-head nipple *1* and swivel nut *2*.

Both types of connection are made up of female and male connectors *4* held to the hose ends by swivel nuts *2*. Housed in each connector is shutoff ball valve *3* that is tightly pressed against its seat in the connector by spring *6*. When the connectors are mated, the ball valves are butted up against each other and forced off their seats to clear the way for oil. When the connectors are uncoupled, springs *6* push the valves into their seats and thus prevent the escape of oil from the hoses and the ingress of dirt into them.

With the rigid-type of hydraulic hose connection, the connectors, when coupled, are held together by swivel nut *5* mounted on the male connector and screwed on the female connector that is threaded on the outside, while with the breakaway connection, the connectors are kept in the mated position by a series of lock balls *7* that are carried in sockets arranged around the periphery of the female connector and fit in an annular groove cut in the male connector. The male connector is fitted in bushing *8* that is mounted on bracket *9* held to the tractor or the machine or implement towed by it. When mating the connectors, the edge of bushing *8* forces the lock balls in the female connector to snap into the groove in the male connector and thus prevent the connectors from parting unintentionally. Should the towed machine or implement break loose from the tractor by accident, the hydraulic hose between them will be stretched tight and will pull the connectors as a unit from the bushing against the pressure of spring *10*. As soon as the lock balls clear the edge of the bushing, the connectors part, thus protecting the hose against damage.

16.2. Hydraulic System Components

OIL TANK. Figure 145 shows the major hydraulic unit of a tractor. The hydraulic fluid (oil) is contained in tank *10*. The oil tank here comprises a body and a cover, whereas on other tractors it is welded from two halves stamped from sheet metal. The tank cover is equipped with filler *5* closed by a plug, breather *6*, oil level dipstick *4*, and oil filter *2*. The tank body serves as a framework for attaching the main hydraulic system components. Hydraulic control valve *9* and the hydraulic traction

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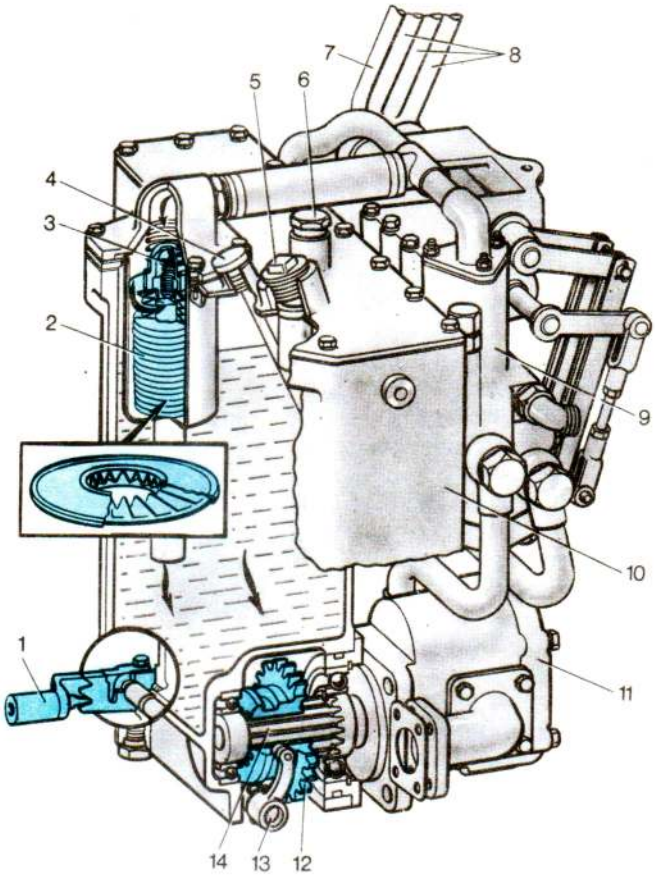
Major hydraulic units of MT3-80 Model tractor

1 – hydraulic pump lever;
2 – oil filter;
3 – oil filter bypass valve;
4 – oil level dipstick;
5 – oil filler;
6 – breather;
7 – hydraulic traction booster control lever;
8 – hydraulic control levers;
9 – hydraulic control (selector) valve;
10 – oil tank;
11 – oil pump;
12 – pump driving gear;
13 – shift fork;
14 – pump drive shaft



booster control unit are attached to the rear wall of the oil tank, and oil pump *11* and its driving gear are installed at the bottom of the tank. The filler neck of the oil tank is equipped with a screen filter. The oil level dipstick is a metal rod bearing three marks labelled by the figure 0 at the bottom, the letter *П* at the top, and the letter *C* in between, the first denoting the minimum oil level, the second denoting the maximum oil level, and the third, the oil level to be maintained when operating a hay stacker.

The oil filter cleans the oil returning to the tank from the system. It consists of a series of disc-shaped screen filter elements arranged in a packet and bypass valve *3*. Should the filter screens get badly clogged with dirt, the increased pressure from the oil will cause the ball valve to open against spring pressure (around 0.3 MPa) and allow the unfiltered oil from the system to bypass the filter and go directly into the tank. During operation, the oil returning from the system seeps through the filter element screens, which remove particles of dirt, and enters a tube with elongated holes in its walls, whence it flows into the tank.

OIL PUMP (Fig. 146). The hydraulic systems of tractors manufactured in this country use the НШ Series gear-type oil (hydraulic) pumps. The individual pumps in this series differ in delivery and sense of rotation, but are similar in construction. A gear-type oil pump of one sense of rotation cannot be replaced by a pump of the opposite sense of rotation. However, any pump of this series can

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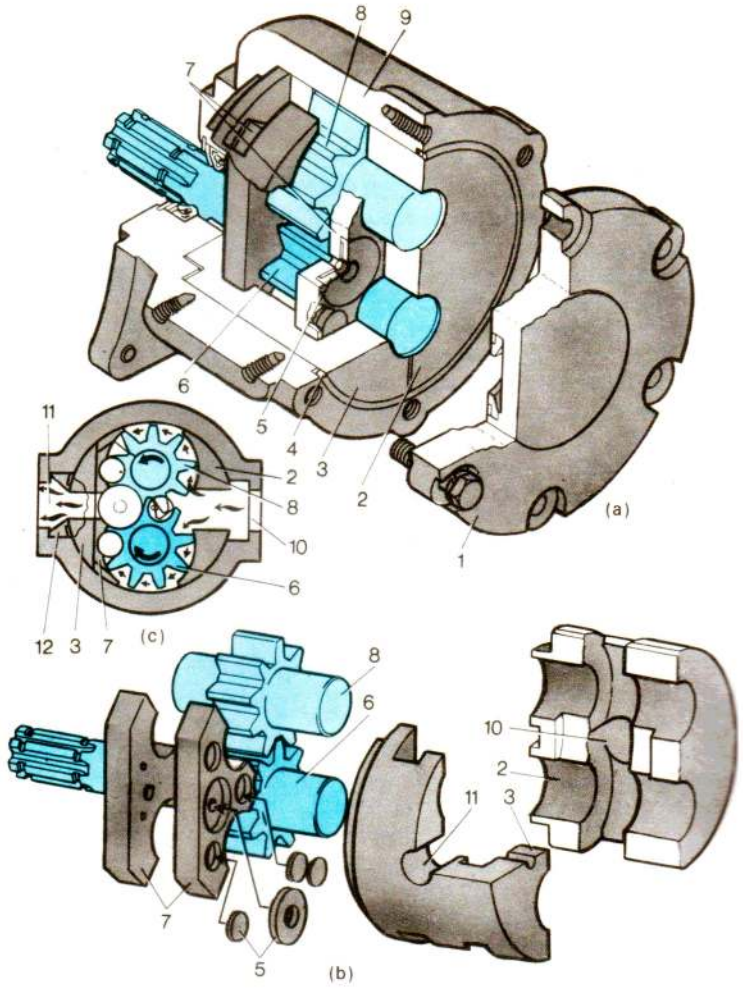
Oil (hydraulic) pump

(a) sectional view of assembled pump;
(b) pump components;
(c) illustrating the principle of pump operation;
1 – pump cover;
2 – bearing block;
3 – pressure block;
4 – rubber O-ring;
5 – cups;
6 – drive gear;
7 – pressure plates;
8 – driven gear;
9 – pump body;
10 – inlet port;
11 – outlet port;
12 – radial seal cup



be rearranged to have its sense of rotation reversed.

The delivery of these pumps is expressed in cubic centimeters per revolution and indicated in their type designation. The pumps are capable of delivering oil at pressures in excess of 16 MPa, which is a fairly high figure. The component parts of the pumps are therefore fabricated to a very high degree of accuracy.

Referring now to Fig. 146, the oil pump consists of body *9* with cover *1*, drive gear *6*, driven gear *8*, bearing block *2*, pressure block *3*, and seals. The oil pump gears are made integral with their shafts. The longer end of the drive gear shaft projects from the pump body and is provided with splines on the outside.

Formed inside the pump body are two chambers: an inlet (suction) chamber with inlet port *10* and an outlet (discharge) chamber with outlet port *11*. The pump gears are arranged between two semi-cylindrical blocks, namely, bearing block *2* and pressure block *3*. The bearing block serves as a common support for both pump gear shafts. The pressure block is pushed against the tooth crowns of the gears by the oil pressure created in the outlet chamber of

the pump, so that the clearance between the gear teeth and the surface of the block is minimized.

Fitted in slots in the pressure block are two shaped pressure plates *7* that rest on the pump gear shafts close to the end faces of the gears. The pressure from the oil in the outlet chamber of the pump pushes the pressure plates tightly against the end faces of the gears. The drive gear shaft is sealed in the pump body by a positive lip-type seal. The pump cover-to-body joint is sealed by rubber O-ring *4*. As the pump gears rotate, a partial vacuum is created in the inlet (suction) chamber of the pump. When the gear teeth unmesh, oil flows to fill in the chamber. This oil is carried in opposite directions around the gears in pockets formed between the gear teeth, the pressure plates, and the bearing and pressure blocks. These components and the oil form a seal, therefore, the oil cannot pass to the inlet side of the pump. The gear teeth mesh on the outlet side, and thereby force the oil from both pockets out into the outlet chamber of the pump and thence out of the pump through the outlet port against the system pressure.

The pump drive gear shaft is splined in to pump drive shaft *14* (see Fig. 145) that is supported by two ball bearings carried in the bottom part of the oil tank body. Splined on to this shaft is pump driving gear *12* that can be slid along the shaft to mesh with or unmesh from an idler gear arranged in the tractor transmission case. The pump driving gear is shifted by means of shift fork *13* that is operated by hydraulic pump level *1* attached to the shift fork shaft. When the lever is locked in the lower notch of its quadrant, the pump drive is disengaged. When the lever is moved up to lock in the upper notch of the quadrant, shift fork *13* slides the pump driving gear along the splines on the drive shaft to mesh the gear with the idler gear in the transmission case. With the engine running, rotation is transmitted to the pump drive gear through the transmission idler gear and pump driving gear *12*. To avoid damage to the pump drive components, the pump should be engaged and/or disengaged only when the engine is stopped. Whenever the tractor is being operated without making use of its hydraulic system, the hydraulic pump should be disengaged.

POWER CYLINDERS (Fig. 147). Power cylinders are designed to raise or lower an agricultural implement directly. Tractors are generally equipped with a single main power cylinder that is pivoted on the rear axle of the tractor and is intended to operate the hitch linkage. There are also remote power cylinders mounted on some trailer-type farm machines and draft implements.

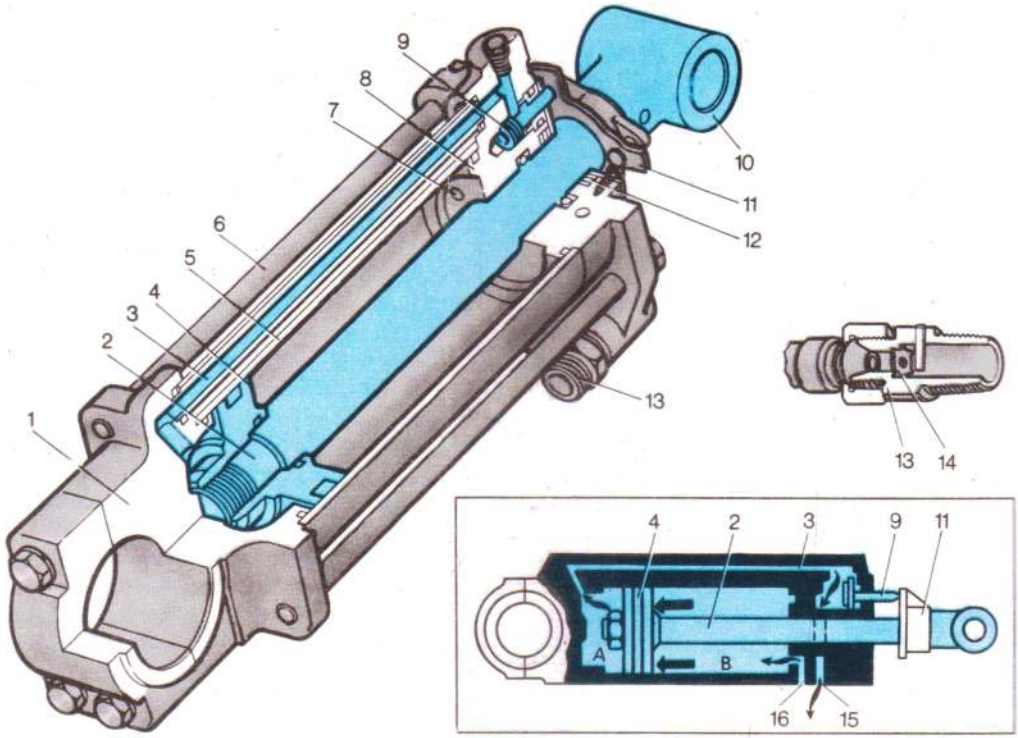
All tractor power cylinders manufactured in this country are of one and the same construction. The only difference between them is the size. The figures included in the type designation of the power cylinders indicate the cylinder bore (inside) diameter. The cylinders are double-acting (two-way) type, i. e., oil can be delivered under pressure into the cylinder space both ahead and behind the piston, or ram.

Each power cylinder consists of body *5*, which is a length of steel tubing with precision-machined inside surface (called the cylinder face), and two covers *1* and *8*. The cylinder body is clamped between the covers by four long bolts *6*. The cylinder houses piston *4* with an annular groove accommodating a rubber sealing ring with non-rigid PVC washers.

The piston is held by a nut to steel rod *2* that passes through a hole in one of the cylinder covers and terminates in a head serving to attach the rod to whatever mechanism the power cylinder is used to operate.

The hole in the cylinder cover is bored to accommodate metal scraper rings *12* intended to remove dirt from the piston rod. There is also valve *9*, whose purpose is to limit the piston stroke, and two holes that communicate with the cylinder spaces, or chambers, ahead and behind the piston and serve to let oil in and out of the cylinder.

If the power cylinder is used, for example, to operate the hitch linkage, the cylinder body is pivoted on the rear axle of the tractor, and its piston rod is attached to the ram, or lift cylinder, arm of the hitch linkage. To lift the implement mounted on the hitch linkage, oil, under pressure, is delivered to the space *A*,



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Power cylinder

(a) construction;
(b) illustrating the principle of cylinder operation;
1 and 8 – cylinder covers;
2 – piston rod;
3 – oil tube;
4 – piston (ram);
5 – cylinder body;
6 – long bolt;
7 – oil passage;
9 – stroke-limiter valve;
10 – piston rod head;
11 – adjustable stop;
12 – scraper rings;
13 – restrictor valve adapter;
14 – restrictor valve;
15 and 16 – oil inlet and/or outlet holes;
A and B – cylinder spaces (chambers)

called the lift chamber, via hole *15* (Fig. 147*b*) in the cylinder cover and tube *3* passing alongside the cylinder body. Oil pressure pushes back the piston, which in turn causes the lift arms of the hitch linkage to move up and raise the implement. At the same time, the oil contained in the space *B* of the cylinder is forced out through hole *16*. To lower the implement, the flow of oil is reversed, i. e., oil is forced into the space *B*, called the lower chamber, via hole *16*, and is expelled from the space *A* through tube *3* and hole *15*. To make the heavy implement hung on the linkage arms lower slowly, use is made of restrictor valve *14* housed in adapter *13* that is screwed in hole *15*. When lowering the implement, the oil escaping from the cylinder pushes the restrictor valve against its seat in the adapter, which leaves only the small hole in the valve for the oil to flow through.

The cylinder body-to-cover joints are sealed by rubber rings grooved into the covers. The piston rod and the stem of valve *9* are also sealed in the cylinder cover by rubber rings.

The piston stroke is adjusted by changing the position of adjustable stop *11* on the piston rod. When the stop is set to rest against the piston rod head, the piston stroke is at its maximum. With the stop in this position, stroke-limiter valve *9* cannot be actuated at all. To reduce the stroke, the stop is slid for the desired distance

down the piston rod and fixed in this position. As the piston goes down the cylinder, oil is forced out of the space *A* through hole *15*, and will continue so until the stop carried on the piston rod depresses the stem of the stroke-limiter valve to push the valve into its seat in the cylinder cover. When the valve fits in its seat, it closes the escape route for the oil from the cylinder through hole *15*. The oil is thus trapped in the space *A* of the cylinder, which prevents the piston from moving further down the cylinder. At the same time, the pressure from the oil on the back of the stroke-limiter valve forces the valve to go deeper into its seat, so that a clearance of 10 to 12 mm is formed between the valve stem tip and the stop. When lifting the implement, the oil forced into the cylinder through hole *15* will push the valve out of its seat and will go to the space *A* of the cylinder. If the clearance between the tip of the stroke-limiter valve stem and the stop becomes less than 10 mm because of the oil escaping from the cylinder through leaks, the stop should be moved 15 to 20 mm from the valve stem, otherwise the valve will not have enough room to leave its seat, and the oil passage to the space *A* of the cylinder will remain closed.

16.3. Hydraulic Control (Selector) Valve

The hydraulic control, or selector, valve directs and controls the flow of oil from the oil pump to the power cylinders. It also automatically switches the hydraulic system of the tractor over to idling after the lifting or lowering of the implement has been ended and protects the system against overloads. Most tractors are equipped with triple-spool hydraulic control valves whose spools can be operated independently.

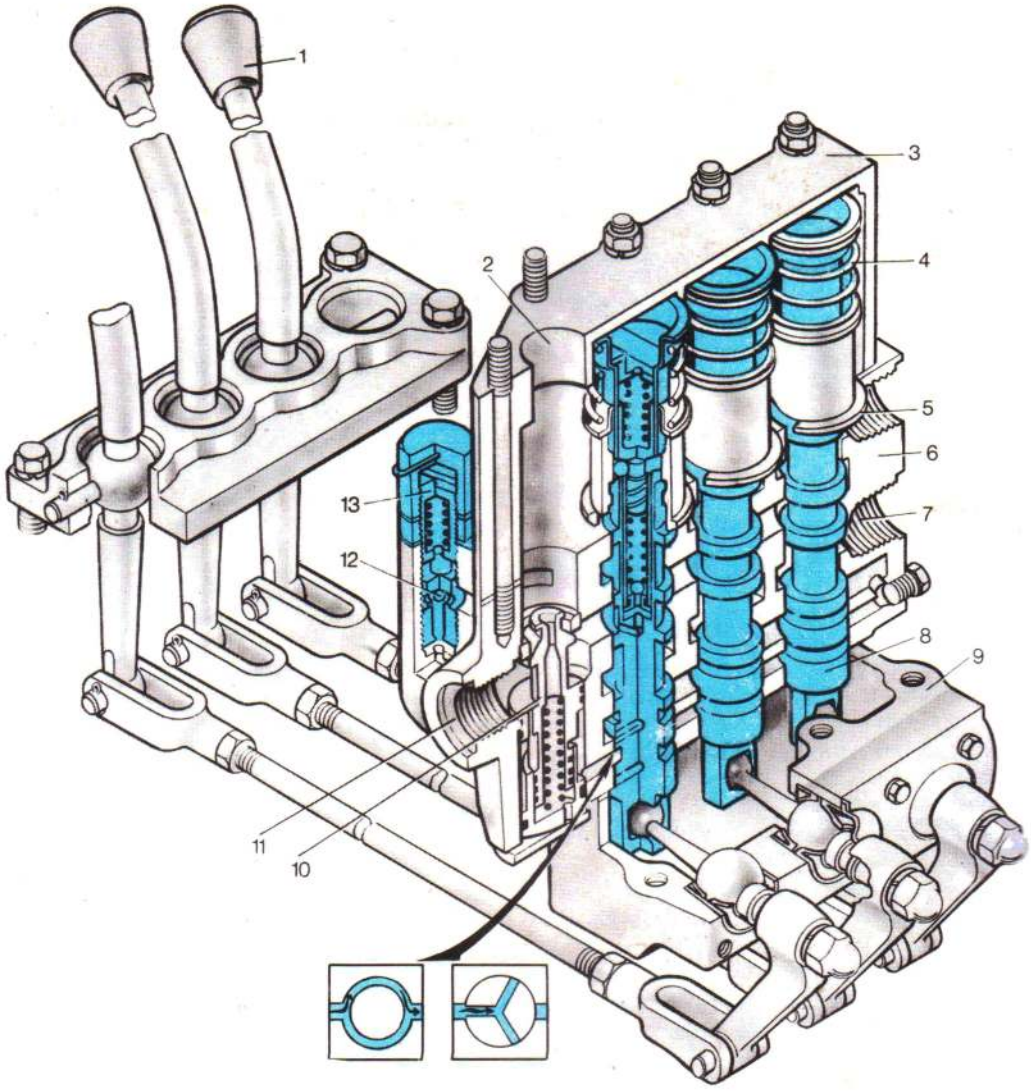
The hydraulic control valve (Fig. 148) consists of body *6*, top and bottom covers, three control spools *8*, bypass valve *10*, and relief valve *12*.

Inside the valve body, there are three precision-machined bores to accommodate the control spools and a series of oil passages. Main inlet passage *11* is connected to the discharge side of the oil pump. Discharge passages *5* and *7*, which are arranged in pairs opposite each control spool, are connected to the power cylinders, the passages arranged level with the letter П (meaning "lift" in Russian) cast on the valve body being connected to the lift chambers of the power cylinders. Arranged opposite the bypass valve is exhaust passage *2* that is connected to the oil tank.

The control spools are fitted to have a very small clearance in their bores in the hydraulic control valve body. Each control spool is operated by hydraulic control lever *1* of its own and controls the operation of a single power cylinder. Each hydraulic control lever can place its associated control spool in four different positions to register the annular grooves in the spool with the appropriate passages in the control valve body. The central position of the control spool is neutral. Pulling back on the hydraulic control lever places the spool into the "LIFT" position. Pushing forward on the lever moves the spool to the "LOWER" position, and pushing further on the lever to move it to its extreme forward position causes the spool to occupy the "FLOAT" position.

With control spool IN THE "LIFT" POSITION (Fig. 149*a*), one of the grooves in the spool connects the discharge chamber of the hydraulic control valve with the lift chamber *A* of the power cylinder, while another groove of the spool makes the lower chamber *B* of the power cylinder communicate with the exhaust chamber of the control valve. In this position, the oil forced into the control valve by the oil pump is directed by the control spool to discharge passage *1* whence it is carried by a hose to the lift chamber of the power cylinder and, pushing on the piston, lifts the implement. At the same time, the oil contained in the lower chamber *B* of the cylinder is forced by the piston out of the chamber and into a hose that conveys it to another discharge passage *2* whence it goes to the exhaust chamber of the control valve and returns to the oil tank through the exhaust passage in the control valve top cover.

With the control spool IN THE "LOWER" POSITION (Fig. 149*b*), it connects the oil pump



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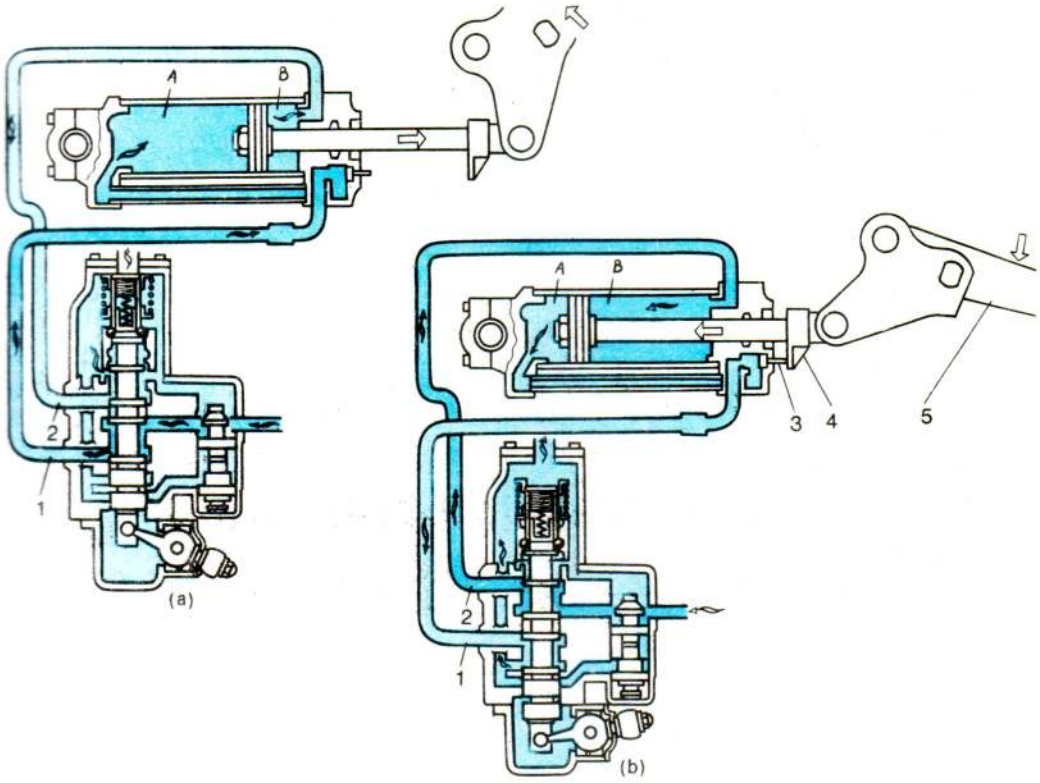
Hydraulic control (selector) valve

1 – hydraulic control lever;
2 – exhaust passage;
3 – top cover;
4 – control spool spring;
5 and 7 – discharge passages;
6 – control valve body;
8 – control (valve) spool;
9 – bottom cover;
10 – bypass valve;
11 – main inlet passage;
12 – relief valve;
13 – adjusting screw

to discharge passage *2*, so that the implement is forced to lower by the oil pumped into the lower chamber *B* of the power cylinder. The oil contained in the lift chamber *A* of the cylinder is expelled into the oil tank through discharge passage *1* and exhaust passage of the control valve.

When the control spool is IN NEUTRAL POSITION (Fig. 150a), its glands cover both



149

Illustrating the operation of the hydraulic control valve

a) control spool in the "lift" position;
b) control spool in the "lower" position;
1 and 2 – control valve discharge passages;
3 – stroke-limiter valve;
4 – adjustable stop;
5 – ram (lift cylinder) arm of hitch linkage;
A – lift chamber;
B – lower chamber

discharge ports. The oil is thus trapped in both chambers of the power cylinder, so that the implement can neither lift nor lower. With the control spool in this position, the oil forced by the oil pump into main inlet passage *4* of the control valve returns to the oil tank through bypass valve *3*.

With the control spool IN THE "FLOAT" POSITION, the oil pump also runs idle, pumping oil into the tank via the bypass valve. However, the spool makes the power cylinder chambers communicate with each other through the control valve, so that the piston can freely move ("float") in the cylinder, following the up and down movement of the implement whose depth wheel follows the field surface (see Fig. 143).

The control spool is locked in any one of its working positions by a special device. The spool is automatically returned to neutral from both the "LIFT" and "LOWER" positions by another device. Both the spool lock and automatic spool return devices are carried on the top end of the spool.

THE CONTROL SPOOL LOCK DEVICE (Figs. 151*a* and *b*) consists of lock balls *6* carried in sockets in control spool *1*, locking plunger *4*, and socket sleeve *5* provided with annular grooves in which the lock balls can fit. Whenever the control spool is moved from neutral and into the "LIFT" or the "LOWER"

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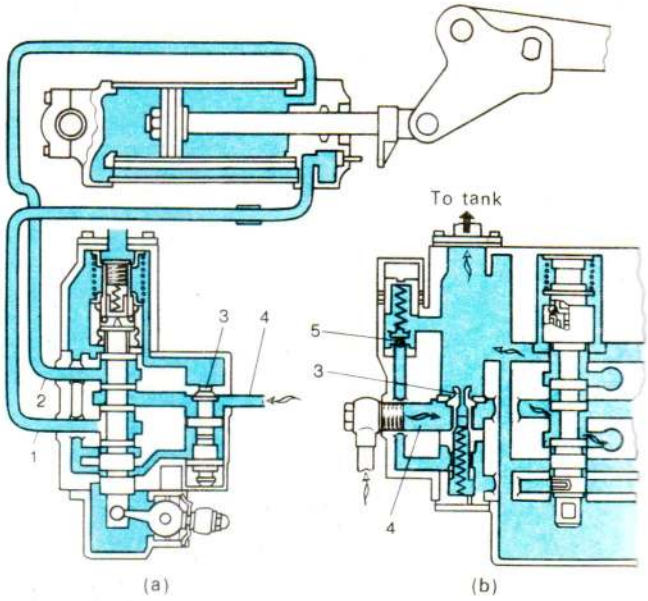
Illustrating the operation of (a) the bypass valve and (b) the relief valve

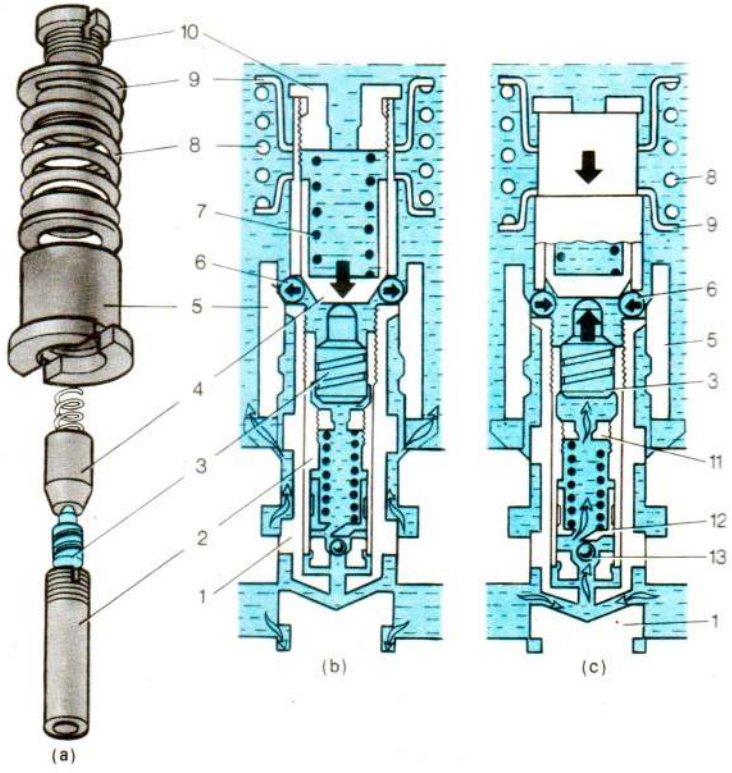
1 and 2 – control valve discharge passages;
3 – bypass valve;
4 – main inlet passage;
5 – relief valve



151

Control spool lock and automatic spool return devices

(a) component parts;
(b) illustrating the operation of the control spool lock device;
(c) illustrating the operation of the automatic spool return device;
1 – control spool;
2 – release plunger barrel;
3 – release plunger;
4 – locking plunger;
5 – socket sleeve;
6 – lock ball;
7 – lock spring;
8 – control spool return spring;
9 – spring cap;
10 – control spool plug;
11 – release plunger seat;
12 – release valve spring;
13 – release valve



position, the taper end of the locking plunger, which is loaded by spring 7, tends to push the lock balls apart, so that when the balls are registered with the appropriate groove in the socket sleeve, they are forced into the groove. As the lock balls fit in the groove, they partly leave their sockets in the control spool and allow the taper end of the locking plunger to go past them. Now, the cylindrical surface of the locking plunger retains the lock balls in the groove in the socket sleeve and thus locks the control spool in position. The socket sleeve is tightly pressed against the control valve body by spring *8* that, at the same time, tends to return the control spool to neutral, acting upon the spool through caps *9*.

THE AUTOMATIC SPOOL RETURN DEVICE (Figs. 151*a* and *c*) becomes operative after the lifting or lowering of the implement is completed. As soon as the power cylinder piston comes to rest against one of the cylinder covers at the end of its lifting or lowering stroke, the oil pressure in the discharge chamber of the hydraulic control valve goes up to 12.5-13.5 MPa. This pressure is sufficient to lift release valve *13* off its seat in barrel *2* against the pressure of spring *12*. The oil entering the barrel through the open valve pushes on release plunger *3*, which in turn causes locking plunger *4* to move up and release lock balls *6*. Spring *8* then forces the balls out of the groove in socket sleeve *5* and returns the control spool to neutral.

If the automatic spool return device should fail, the oil pressure in the discharge chamber of the control valve will rise to 16 MPa, at which point relief valve *5* (see Fig. 150*b*) opens to let the oil escape to the oil tank through the exhaust chamber of the control valve.

The operation of the relief valve is attended by a characteristic noise, and the oil escaping through the valve gets highly heated. Therefore, if the automatic spool return device fails, the spool should be returned to neutral manually, i.e., by operating the hydraulic control lever.

16.4. Hitch Linkage and Drawbar Hitch

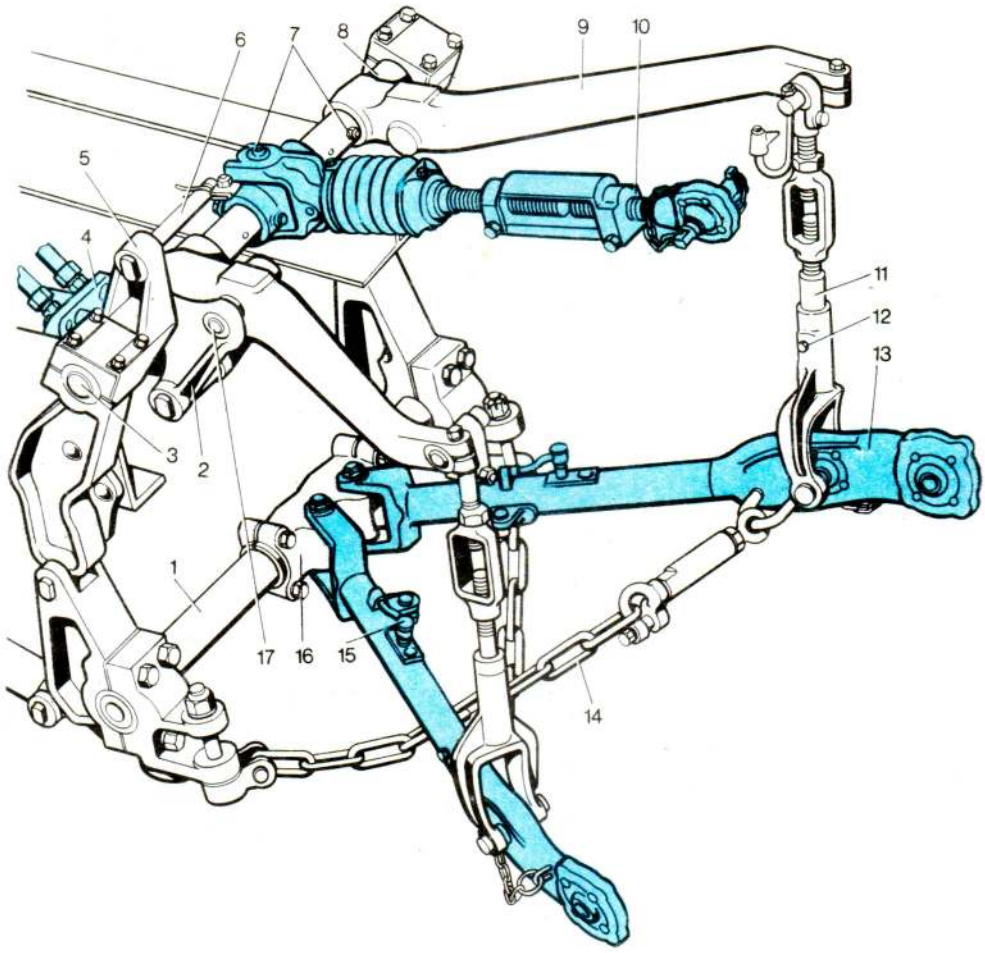
THE HITCH LINKAGE (Fig. 152) serves for attaching fully mounted and semi-mounted implements to the tractor and also to lower the implements into work and lift them out of work and into the travel, or transport, position. Semi-mounted implements have a depth wheel or wheels fitted to them, whilst fully mounted implements have no wheels at all. Both classes are known as mounted implements. The hitch linkage is arranged at the rear of the tractor and can be adapted for use with both two- and three-point hitch systems. With an implement attached to a tractor in this way, they together form a single working unit. Such working units possess some advantages over tractor-and-draft-implement units in that they have better manoeuvreability and lower fuel consumption per unit of work done. Also, mounted implements are relatively less metal-intensive than their draft counterparts.

Referring now to Fig. 152, the hitch linkage consists of lower linkage axle *1* and top linkage axle *3*, which are held to the tractor frame, top link *10*, two lift arms *9*, and two lower, or draft, links *13* that are hinged to the lift arms.

The lift arms are splined to the ends of hollow rockshaft *8* (also known as the lift shaft) that are supported by plain cast-iron bushings on the top linkage axle. Freely mounted on the left-hand end of the rockshaft is ram, or lift cylinder, arm *2* which is connected to the left-hand lift arm in a one-way manner, so that the ram arm can only push and not pull on the lift arm.

When operating mounted implements that require positive, or power, penetration, the ram arm is rigidly connected to the lift arm by means of a pin inserted in hole *17*. It is prohibited to use the rigid connection between the ram and lift arms when working with implements not requiring positive penetration, such as plows, drills, or cultivators, for this may cause damage to the implements.

Mounted implements are attached to the ends of the top and lower links by ball joints. Placing the hydraulic control lever into the



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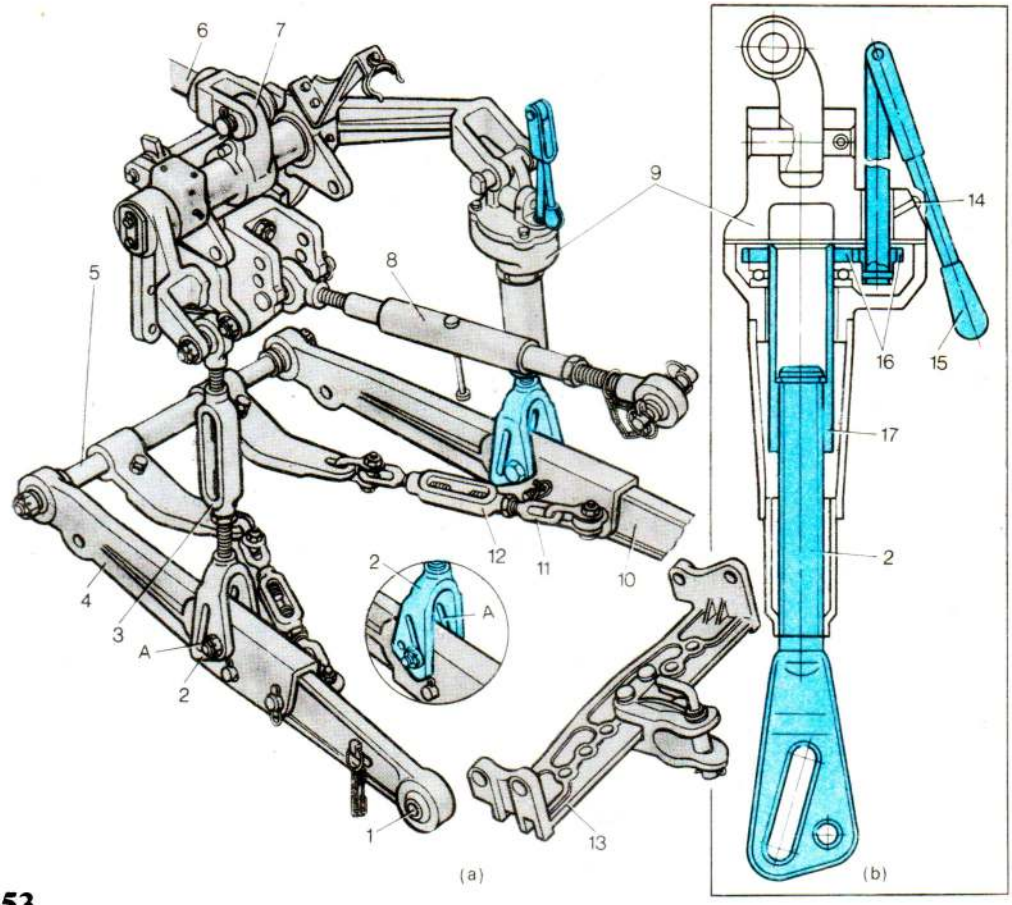
Hitch linkage of T-150K Model tractor

1 – lower linkage axle;
2 – ram (lift cylinder) arm;
3 – top linkage axle;
4 – power (lift) cylinder;
5 – stop arm;
6 – stop pin;
7 – grease fittings;
8 – rockshaft (lift shaft);
9 – lift arm;
10 – top link;
11 – lift link (rod);
12 – lock pin;
13 – lower (draft) link;
14 – check (sway) chain;
15 – lower adjuster plunger;
16 – central hitch head;
17 – pin hole

"LIFT" position causes the power (lift) cylinder to extend and, with the piston rod acting on the ram arm, turn the rockshaft together with the lift arms. The lift arms pull on the lift links which in turn pull on the lower links to lift the implement attached to the links out of work and into the travel position.

The two-point hitch system is used to operate plows. With this system, the front ends of the lower links are brought together and connected to central hitch head *16*, one of the links being



153

Three-point hitch linkage

(a) construction;
(b) adjustable lift link;
1 – ball joint (lower hitch point);
2 – lift link fork;
3 – left-hand lift link;
4 – lower link front part;
5 – lower linkage axle;
6 – lift cylinder rod;
7 – ram (lift cylinder) arm;
8 – top link;
9 – right-hand lift link adjuster gear drive;
10 – lower link rear part;
11 – check (sway) chain;
12 – check chain turn-buckle;
13 – drawbar hitch;
14 – grease fitting;
15 – handle;
16 – gears;
17 – lift link tube;
A – slot

rigidly held to the head and the other pivoted on it.

The central hitch head can be both aligned with the centerline of the tractor and displaced for a certain distance to the right.

The three-point hitch system (Fig. 153) is employed when operating broad-gang or wide-cut implements, such as drills, cultivators and harrows. With this system, the mounted implements are arranged symmetrically relative to the centerline of the tractor. As distinct from the hitch linkage shown in Fig. 152, the ram arm here is arranged above the rockshaft. Therefore, expanding the lift cylinder causes the implement to lower.

Check, or sway, chains *11* (item *14* in Fig. 152) serve to limit the sideways movement of the mounted implements. When operating broad-gang implements, the bolts connecting the lift links to the lower links are inserted in slots *A* provided in lift link forks *2*.

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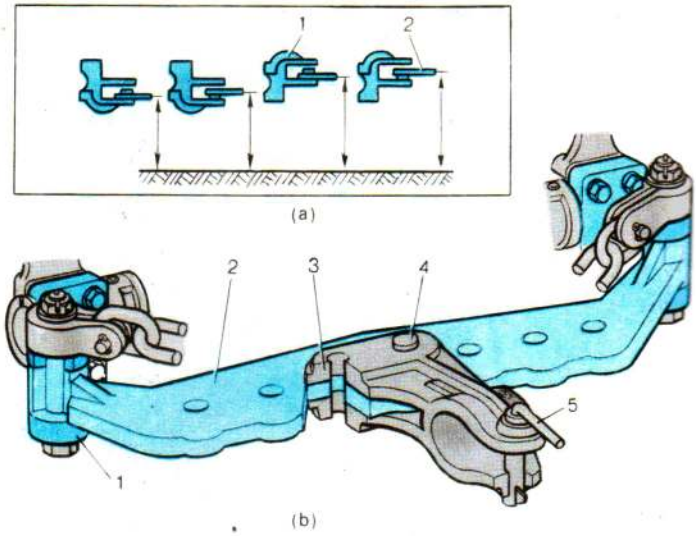
Drawbar hitch

(a) illustrating vertical hitching;
(b) construction;
1 – yoke;
2 – drawbar;
3 – hitch clevis;
4 – clevis pin;
5 – implement hitch pin



The hitch linkage allows for adjustment of the lengths of the top and lower links, and also the length of the right-hand lift link. The length of the top link is adjusted so as to make level the points of the front and rear shares of e. g. a plow when lowered into work. If the implement tilts to the side, it is then levelled by changing the length of the right-hand lift link. When operating mounted implements, the length of the left-hand lift link is not adjusted. Its length must remain constant.

To facilitate changing the length of the adjustable lift link, the lift link adjuster may be made in the form of a screw mechanism with gear drive *9*. The adjuster drive comprises a pair of spur gears *16* and is operated by handle *15* that is hinged to the driving gear shaft. The component parts of the adjuster are lubricated with grease injected through fitting (nipple) *14*.

Some tractors may have drawbar hitch *13* mounted on the lower links of their hitch linkage for attaching drawn implements. The top link of the hitch linkage must never be used as a hitch point for drawn equipment lest the tractor should overturn.

With other tractors, THE DRAWBAR HITCH (Fig. 154) is mounted independently of the hitch linkage, the linkage being raised to its uppermost position. The drawbar hitch consists of drawbar *2*, hitch clevis *3*, and implement hitch pin *5*. The drawbar is bolted to yokes *1* held to the rear coupling brackets of the tractor frame.

The drawbar is provided with cast holes for the clevis pins. With symmetrical drawn equipment, the central clevis pin is inserted in the central hole in the drawbar. If the tractor teamed with a draft implement pulls to the right during operation, the hitch clevis is displaced to the left of the tractor centerline; conversely, if the tractor pulls to the left, the hitch clevis is displaced to the right. This adjustment is called horizontal hitching.

The height of the attachment point for the implement can be adjusted by turning through 180° the drawbar on its yokes and the yokes on their brackets. This adjustment is known as vertical hitching.

The hitch clevis is usually connected to the drawbar by the central pin alone, this reducing the loss of tractor power on turns. However. when the tractor is teamed with a machine requiring drive from the PTO shaft, the hitch clevis is rigidly connected to the drawbar by two pins.

Farm tractor modifications supplied without the hitch linkage still have the lower linkage

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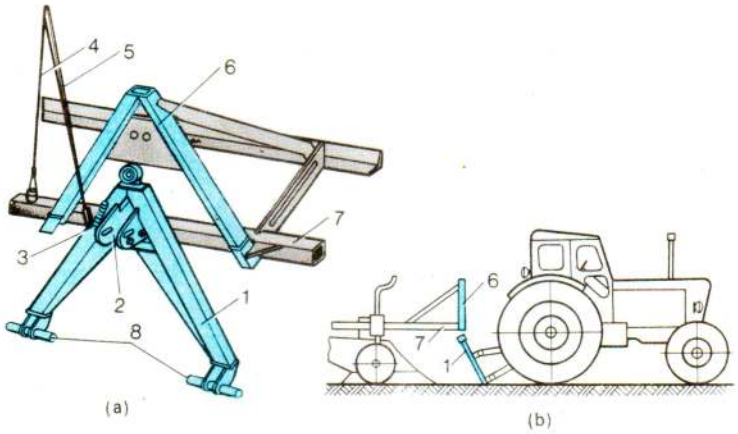
Automatic (pickup) hitch

(a) construction;
(b) illustrating the hitching of implement;
1 – automatic hitch frame;
2 – cleats;
3 – spring;
4 – cable;
5 – lever;
6 – lock;
7 – implement hitch frame;
8 – pins



axle installed in order to provide for rigid connection between the rear coupling brackets of the frame.

Drawn implements are attached to the hitch clevis by means of implement hitch pin *5* with a locking pin welded to it at the top and a latch attached at the bottom.

To facilitate attaching implements to the tractor, use is made of AN AUTOMATIC, OR PICKUP, HITCH (Fig. 155).

The automatic hitch comprises frame *1* mounted on the hitch linkage of the tractor and lock *6* welded to the hitch frame of the implement. Fitting of the implement to the tractor entails reversing the tractor to the implement with the automatic hitch frame down, and stopping when the top of the frame comes in line with the lock on the implement. The hitch linkage is then raised until the automatic hitch frame completely engages the lock. Finally, the automatic hitch frame is latched in the lock.

Many wheeled tractors are equipped with A HYDRAULIC, OR PICKUP, HOOK (Fig. 156). The hook is used for towing two-wheeled trailers and provides for quick hitching and unhitching of the tractor to the trailer without any need for the driver to leave his driving seat.

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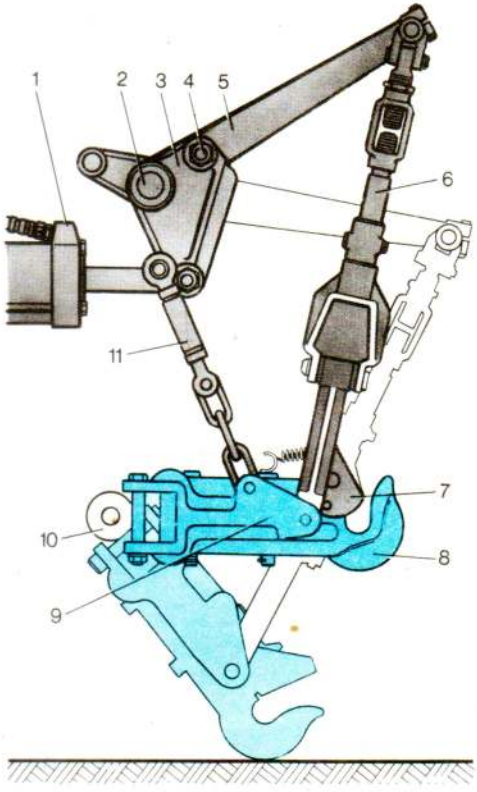
Hydraulic (pickup) hook

1 – power cylinder;
2 – top linkage axle;
3 – ram arm;
4 – connecting pin;
5 – lift arm;
6 – lift link;
7 – latch;
8 – hook;
9 – hook bar;
10 – lower linkage axle;
11 – check link



Hook *8* is suspended from lift arms *5* by two lift links *6*, and its front end is pivoted to the lower linkage axle of the tractor frame. The hook is lifted and lowered by operating the hydraulic control lever that controls the operation of the rear main power cylinder of the tractor hydraulic system. With the hook in the raised position, its mouth is automatically closed by latch 7. When towing a loaded trailer, additional weight is transferred to the rear wheels of the tractor through the hook, which increases the adhesion weight of the tractor, hence its traction. When the tractor is used to operate mounted implements, the hook is placed in a horizontal position and fixed to a special bracket.

16.5. Traction Boosters

If some of the weight of the implement is transferred to the rear driving wheels of the tractor, its wheel adhesion (traction) will be improved. It is exactly for this purpose that traction boosters serve. They are employed on row-crop tractors and may be either mechanical or hydraulic type.

MECHANICAL TRACTION BOOSTER (Fig. 157). When the lower links of the hitch linkage are arranged horizontally, the implement draft, i. e., the draft resistance due to the action of the soil on the implement in work, loads the lower links in tension and the top link in compression. With the implement attached to the tractor in this way, the driving wheels of the tractor are loaded by the adhesion weight of the tractor, while the weight of the implement, say a plow, is carried by its depth (support, or thrust) wheel and shares. If the point of attachment of top link *1* to the tractor is arranged to lie lower, the compressive force acting on the top link will be pointed down at some angle to the horizontal. The vertical component of this force will add load on the driving wheels of the tractor. At the same time, an equal force will subtract, almost to the same degree, from the weight supported by the depth wheel and shares of the plow. To take advantage of this effect, the front end of top link *1* of the hitch linkage is attached to bracket *2* with a series of vertical holes that is held to the rear axle housing of the tractor. The lower the point of attachment of the top link to the bracket, the greater the vertical component F_v of the compressive force acting on the top link that adds weight to the rear wheels of the tractor. Hence, the greater the tendency of the tractor driving wheels to slip, the lower should be the point of attachment of the top link to the bracket to compensate for this tendency.

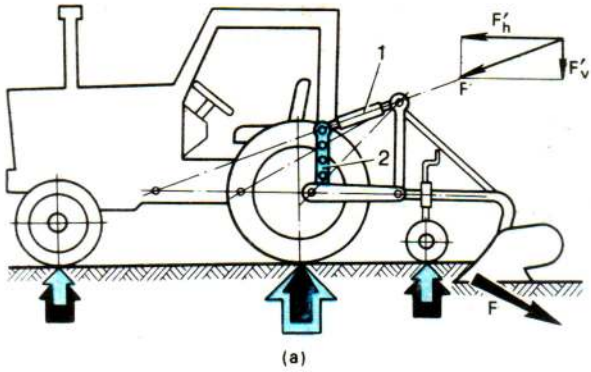
Mechanical traction boosters are disadvantageous in that they can be used only with implements whose draft exceeds their own weight. Hydraulic traction boosters are free from this disadvantage.

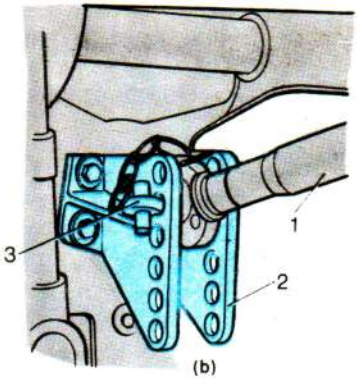
HYDRAULIC TRACTION BOOSTER (Fig. 158). The booster consists of a traction control unit and a hydraulic accumulator that are inserted in the tractor hydraulic system between the hydraulic control valve and the main power cylinder.

The principle on which the hydraulic traction booster operates is based on the fact that in attempting to lift a weight, before it ever moves, some of its weight is transferred to whoever or whatever is trying to lift it. For example, if a man tries to lift a weight of, say, 100 kgf, as he gradually increases his effort to lift it, so will the weight transferred to him gradually increase. This means that the pressure exerted by his feet on the ground will gradually increase until, when he lifts the weight, the ground pressure will be the man's weight plus 100 kgf. The traction control unit is designed so that the hydraulic system only attempts to lift the weight of the implement, and the weight on the rear wheels of the tractor is increased without any actual lifting of the implement taking place.

THE TRACTION CONTROL UNIT (Fig. 158*a*) is installed beside the hydraulic control valve. It consists of body *1*, control spool *2*, pressure regulator valve *7*, shutoff valve *16*, check valve *6*, and relief valve *4*.

The control spool is arranged in the lower part of the traction control unit and is provided with grooves and recesses in its front portion. The rear end of the control spool is attached to control arm *12* held fast on a shaft that projects outward and carries a control lever on its end





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Mechanical traction booster

(a) illustrating the principle of operation;
(b) construction;
1 – top link;
2 – bracket;
3 – linch pin;
F – implement draft force;
F' – compressive force in top link;
F'_v and F'_h – vertical and horizontal components of compressive force in top link

The control lever can be locked in three positions: "ON", "OFF", and "LOCKED". Locking is effected by means of five lock balls *13* that are carried in sockets in cage *14* and fit in one of the three respective grooves in the control spool. The lock ball cage is held tight against the cover of the traction control unit by a spring.

The control lever can also be placed in a fourth – "RELEASE PRESSURE" – position, but cannot be locked there.

Housed in the upper part of the traction control unit is pressure regulator valve *7* loaded by spring *8* that tends to move the valve to the left (in the figure). The valve is acted upon by the pressure of the oil that is forced by the oil pump into the discharge chamber of the traction control unit. When this pressure exceeds the pressure exerted on the valve by spring *8*, the valve is forced to move to the right. The spring pressure on the valve can be adjusted by means of handwheel *11* fitted on the end of adjusting screw *10*.

Inside the pressure regulator valve, there is relief valve *4* that is loaded by spring *3* whose pressure is adjusted concurrently with that of the pressure regulator valve spring. The relief valve spring pressure is selected so as to make the opening pressure of the relief valve exceed that of the pressure regulator valve by 0.8 to 1.5 MPa.

Arranged beside the pressure regulator valve is check valve *6* whose purpose is to let oil pass through in one direction only, namely, from the discharge space of the traction control unit to the hydraulic accumulator of the traction booster.

THE HYDRAULIC ACCUMULATOR (Fig. 158*b*) is mounted on the axle sleeve of the left rear wheel. It consists of thin-walled shell *18* that houses movable cylinder *21* and stationary piston *22* held to rod *20*. The piston rod is fixed to the hydraulic accumulator cover, and the cylinder is pressed against the cover by power spring *19*. The piston is sealed inside the cylinder by cups.

When the hydraulic accumulator is being charged, oil, under pressure, enters the space between the cylinder and piston and forces the cylinder to move against the pressure of the power spring and thus compress the spring. When the tractor operates with the traction control unit in the "ON" position, the hydraulic accumulator is connected to the main power cylinder. The oil pressure created by the power spring in the hydraulic accumulator produces an uplift pressure in the power cylinder. In the rear wall of the hydraulic accumulator shell, there is a hole closed by plug *23* that serves to drain oil leaking past the seals.

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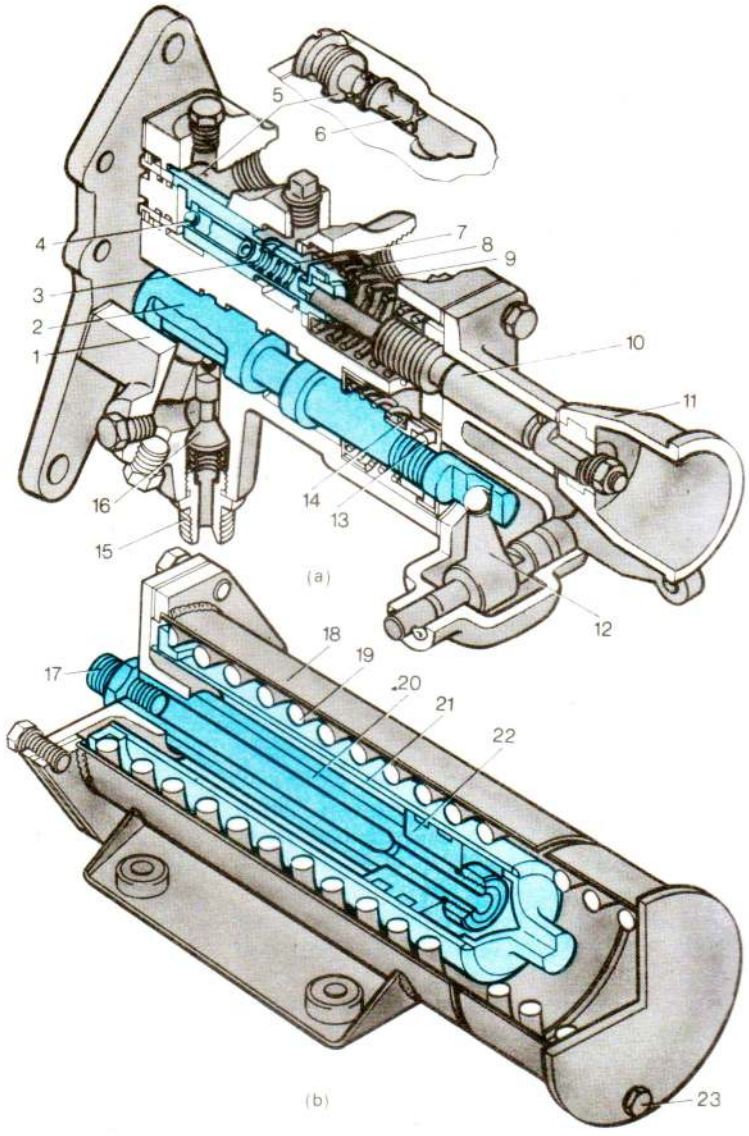
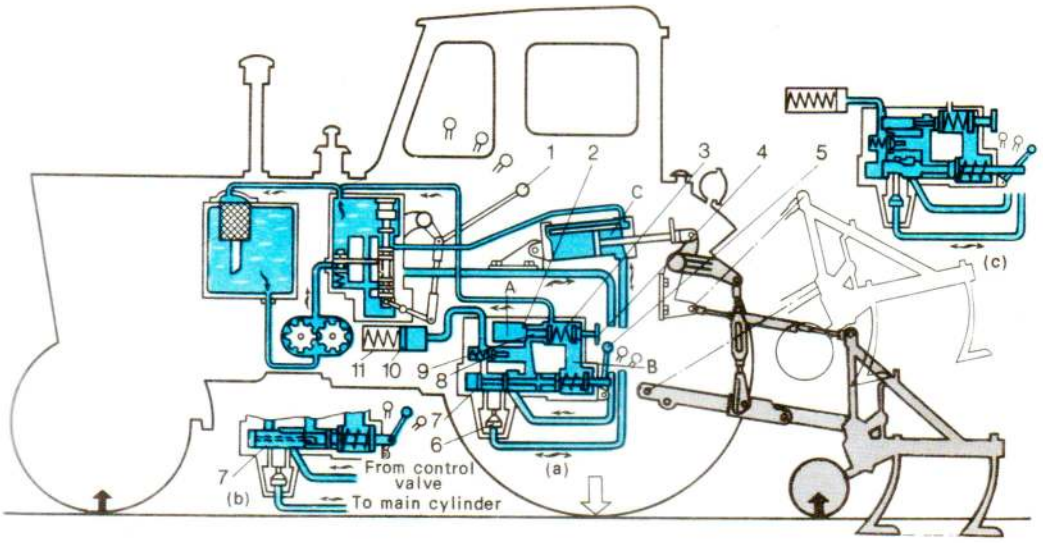
Hydraulic traction booster of MT3-80 Model tractor

(a) traction control unit;
(b) hydraulic accumulator;
1 – body;
2 – control spool;
3 – relief valve spring;
4 – relief valve;
5 – oil passage connecting hydraulic accumulator, check valve, and pressure regulator valve chambers;
6 – check valve;
7 – pressure regulator valve;
8 – pressure regulator valve spring;
9 – exhaust port to oil tank;
10 – adjusting screw;
11 – handwheel;
12 – control arm;
13 – control spool lock ball;
14 – lock ball cage;
15 – fitting for hydraulic hose from main power cylinder;
16 – shutoff valve;
17 – fitting for oil line from traction control unit;
18 – shell;
19 – power spring;
20 – piston rod;
21 – cylinder;
22 – piston;
23 – drain plug



With the hydraulic traction booster control lever in the "ON" position (Fig. 159*a*), oil is delivered under pressure from the hydraulic control valve to the discharge chamber *A* of the traction control unit. At the initial moment (not illustrated in the figure), pressure regulator valve *9*, under the pressure of spring *3*, closes the exit for oil into the exhaust chamber *B* of the traction control unit. Having no escape route from the discharge chamber, the oil. forced by the oil pump, pushes check valve *8* off its seat and goes to the hydraulic accumulator to charge it. As soon as the pressure in the accumulator becomes high enough to overcome the



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Illustrating the operation of the hydraulic traction booster

a) "ON" position;
b) "OFF" position;
c) "LOCKED" position;
1 – hydraulic control lever;
2 – traction control unit;
3 – pressure regulator valve spring;
4 – handwheel;
5 – hydraulic traction booster control lever;
6 – shutoff valve;
7 – control spool;
8 – check valve;
9 – pressure regulator valve;
10 – hydraulic accumulator piston;
11 – hydraulic accumulator;
A – discharge chamber;
B – exhaust chamber;
C – power cylinder lift chamber

spring pressure on the pressure regulator valve, the valve is forced to move to the right and connect the discharge chamber *A* to the exhaust chamber *B*, as illustrated in Fig. 159*a*. From this moment on, the oil pumped into the discharge chamber goes back to the oil tank via the exhaust chamber. The resulting drop of pressure in the discharge chamber causes the check valve to close, and the pressurized oil contained in the hydraulic accumulator goes through open shutoff valve *6* to the lift chamber *C* of the power cylinder to apply an uplift pressure to its piston, which transfers some of the weight of the implement to the rear wheels of the tractor. This gives better wheel adhesion (traction).

The uplift pressure in the power cylinder can be varied in the range 0.8 to 2.8 MPa by turning pressure regulator handwheel *4*. The pressure regulator valve is usually set for the maximum uplift pressure in the power cylinder, i.e., the pressure regulator handwheel is turned clockwise until the adjusting screw it is attached to is screwed all the way in. If the depth wheel of the implement fails to follow the field surface, the uplift pressure should be reduced by turning the handwheel counterclockwise. This decreases the initial compression of spring *3* that loads pressure regulator valve *9*.

With the hydraulic traction booster control lever in the "OFF" position (Fig. 159*b*), control spool *7* connects the hydraulic control valve directly to the main power cylinder. At the same time, it closes the oil inlet to the traction control unit, so that the hydraulic traction booster is inoperative and the tractor hydraulic system operates as described in Section 16.3.

If the implement is to be transported for a long distance, the hydraulic traction booster control lever should be placed in the "LOCKED" position (Fig. 159*c*). In this case, the main power cylinder is disconnected from

the hydraulic system by shutoff valve *6* closing the exit for oil from the lift chamber of the power cylinder. This prevents the oil escaping from the cylinder past the control spools in the hydraulic control valve and traction control unit.

With the hydraulic traction booster control lever in the "RELEASE PRESSURE" position, the lift chamber *C* of the power cylinder is connected to the exhaust chamber of the hydraulic control valve. As mentioned earlier, the control lever cannot be locked in this position, and so the lever is automatically returned to the "ON" position as soon as the driver releases the lever.

16.6. Automatic Draft and/or Position Control System

When operating an implement with the hydraulic control lever in the "FLOAT" position, or with the hydraulic traction booster control lever in the "ON" position, the depth of work depends on the setting of the depth wheel or wheels of the implement. Such a system of controlling the implement is known as depth control system.

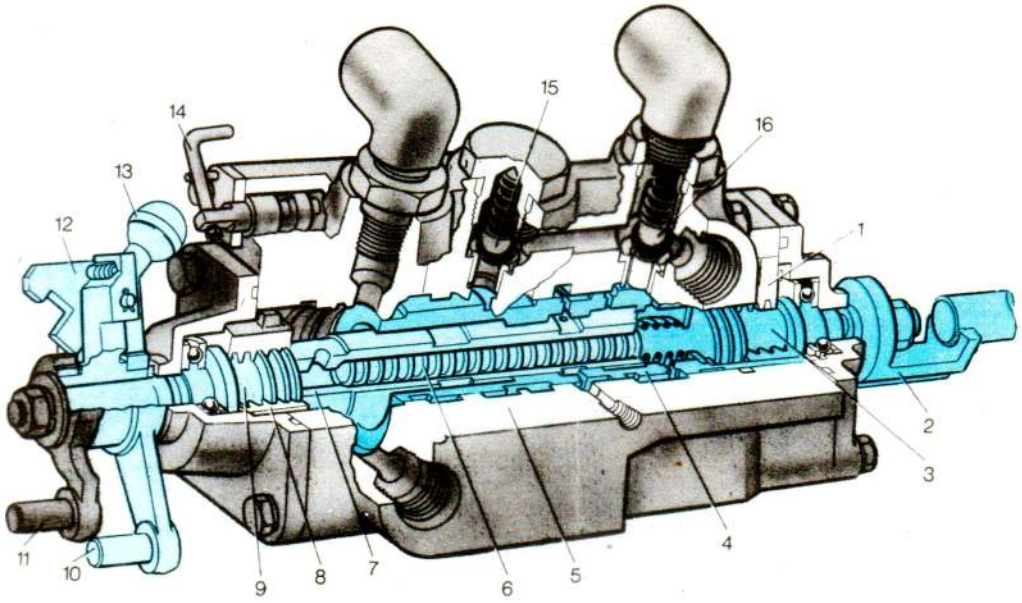
Automatic draft control systems will automatically raise or lower an implement as the draft of the attached implement increases or decreases. The sensing device that tells the hydraulic system to lower or raise the hitch linkage is located on either the lower links or the top link, depending on the size of the tractor. The position of the hand control lever, in effect, establishes the draft to be maintained. For example, a draft control system on a tractor pulling a plow will raise and lower the plow to maintain a constant force on the sensing device.

Automatic position control systems provide automatic control of an attached implement and allow the operator to preselect and to position the implement, as determined by the position of the hand control lever. The relative position of the hand lever and the power cylinder are always identical. Within the limit of the relief valve controlling the maximum pressure, the power cylinder will automatically move the implement to its predetermined position relative to the tractor undercarriage and maintain it there, regardless of the draft of the implement or any leakage in the system.

Hydraulic systems of some row-crop tractors include special devices which, in addition to depth control, provide for automatic draft, position, and combination (depth-and-draft or depth-and-position) control. Automatic draft and position control systems are advantageous in that they eliminate the need for agricultural implements to have depth wheels fitted to them, so that the weight of the attached implement is transferred to the rear wheels of the tractor, which increases its adhesion weight.

Consider an automatic draft and/or position control system. The system includes a hydraulic draft and/or position control unit, draft and position sensing devices, and an operating mechanism.

THE HYDRAULIC DRAFT AND OR POSITION CONTROL UNIT (Fig. 160) is mounted on the main power cylinder bracket. It is essentially a hydraulic control valve of special design. Body *5* of the unit houses movable sleeve *4* in which fits spool valve *2*. Spring *6* tends to move the valve and the sleeve apart and push them against their respective nuts *8* and *1*. The nuts are screwed on screws *9* and *3*, respectively. When either screw is turned one way or the other, its associated nut is caused to move axially, either against the pressure of spring *6* or aided by it. By operating control mode selector lever *13*, spool valve screw *9* can be connected either to arm *10* or to arm *11*, which in turn are connected respectively to the position and draft sensing devices by means of control rods. Movable sleeve screw *3* is connected by shaft *2* with control lever *6* (Fig. 161) arranged in the driver's cab. The draft and/or position control range is shown in blue ink on control lever quadrant *5*. In operation, the control lever is placed in such a position on the quadrant as provides for the desired depth of work. Pushing the lever forward increases the depth of work. Once the required depth of work is established, the maximum forward stroke of the control lever is limited by means of stop *3*.



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Hydraulic draft and/or position control unit of MT3-80 Model tractor

1 – movable sleeve nut;
2 – control shaft;
3 – movable sleeve screw;
4 – movable sleeve;
5 – body;
6 – expansion spring;
7 – spool valve;
8 – spool valve nut;
9 – spool valve screw;
10 – position control arm;
11 – draft control arm;
12 – control mode selector lever lock;
13 – control mode selector lever (set in position control mode);
14 – correction rate regulator valve lever;
15 and 16 – valves

Provision is made in the control unit for a regulator valve, operated by lever *10*, which determines the position of the bypass valve in the hydraulic control valve of the tractor hydraulic system when the latter effects a corrective raising action. This provides a means for adjusting the rate of such corrective actions. The greater the extent to which the regulator valve is closed, the greater the quantity of oil returning to the oil tank through the bypass valve during a corrective raising action of the system, hence the slower the rate of the action.

Draft and/or position control unit *I* (Fig. 162) is connected by metal hydraulic lines *C*, *D*, *E*, and *G* to hydraulic control valve *III*, the discharge chamber of oil pump *IV*, and traction control unit *VII*, and by high-pressure hydraulic hoses *A* and *B* with power cylinder *II*.

Draft sensing device 18 is incorporated in bracket *17* to which top link *16* of the hitch linkage is attached. Compressive forces are sensed by leaf spring *19*, while tensile forces are sensed by four coil springs *20*. When the thrust transmitted by the top link of the hitch linkage to bracket *17* becomes high enough to deform (compress or expand) the springs (called the control, or load, springs), the bracket starts moving, and this motion is transmitted to the spool valve of the draft and/or position control unit through arm *22* and draft control rod *12*.

The position sensing device is ram arm *15* of the hitch linkage. The motion of the ram arm is transmitted to the spool valve by position control rod *13*.

OPERATION. With both draft- and position-control modes of operation, the power cylinder is controlled only by control lever *2* of the draft and/or position control unit. The

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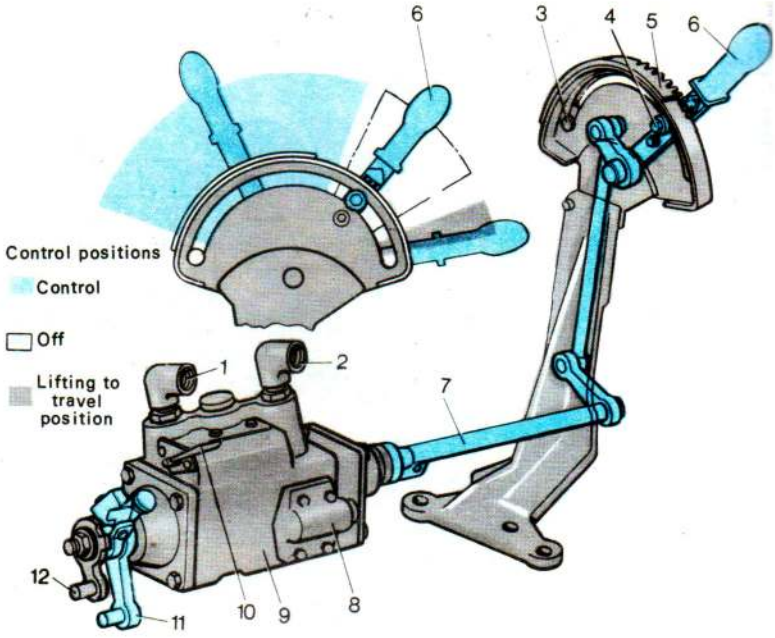
Operating mechanism of the automatic draft and/ or position control system

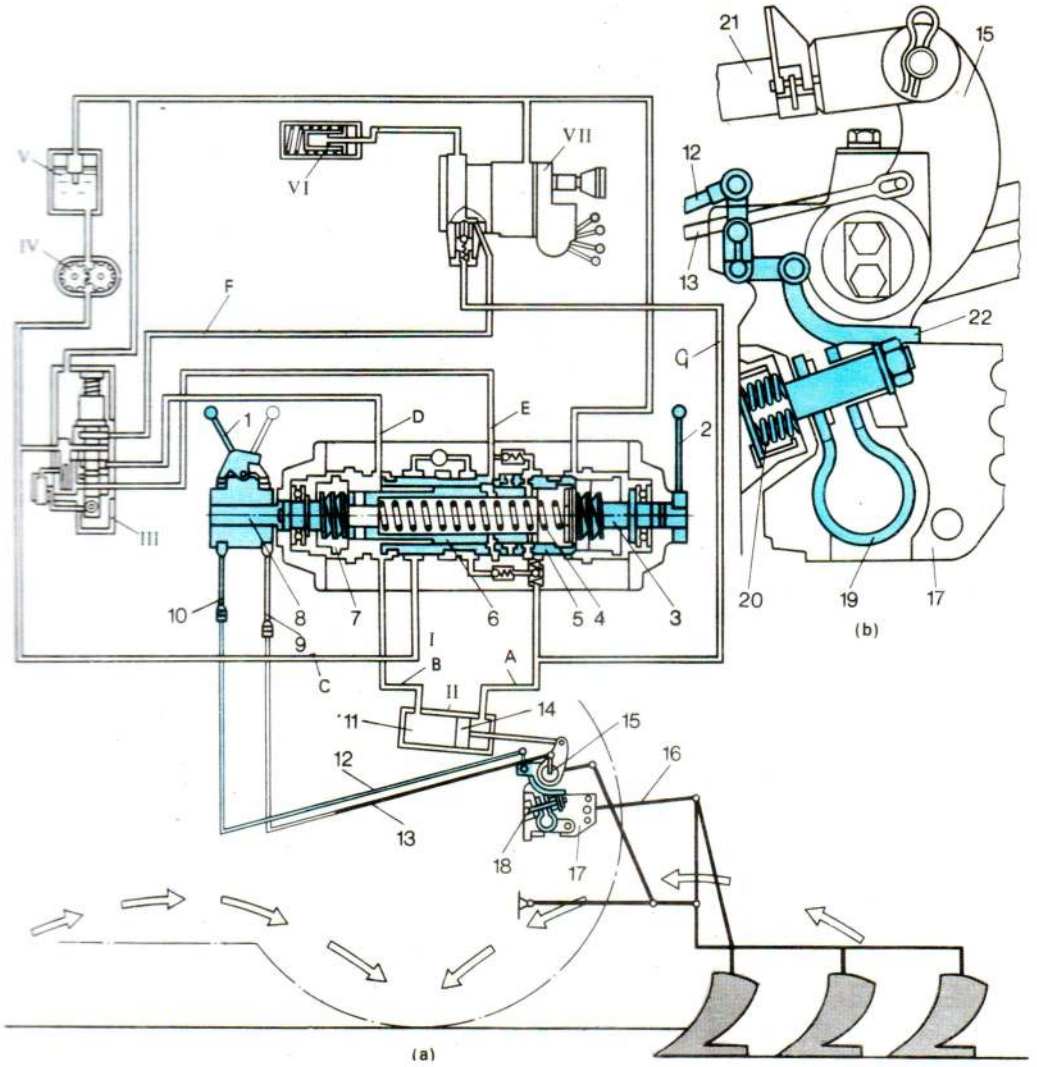
1 and 2 – fittings for power cylinder hydraulic hoses;
3 – adjustable stop;
4 – latch gear to retain control lever in "OFF" position;
5 – control lever quadrant;
6 – control lever;
7 – control shaft;
8 – check valve cover;
9 – body;
10 – correction rate regulator valve lever;
11 – position control arm;
12 – draft control arm



hydraulic control lever is in this case placed in neutral, and the hydraulic traction booster control lever is set into the "OFF" or "LOCKED" position. Then the mode of operation is selected by operating control mode selector lever *1* to connect spool valve screw *8* either with draft control arm *10* or with position control arm *9*. Then control handle *2* is placed into the desired position.

WITH AUTOMATIC DRAFT CONTROL, any variation in the thrust in the top link of the hitch linkage due to changes in the implement draft resulting from varying soil conditions or unintentional variations in the depth of work causes some change in the extent of deformation of the control (load) springs in draft sensing device *18*. The corresponding draft error signal is then transmitted through the draft control rod and arm to spool valve screw *8* which causes its nut *7* to move spool valve *6* either way from its neutral position. In one case, the valve will move to connect the lift chamber of the power cylinder with the exhaust to the oil tank, so that the ram will lower the implement, whereas in the other case, the valve will connect the lift chamber to the discharge line *F* to raise the implement. In either case, the movement of the ram is automatically directed so as to make the necessary adjustment to the position of the implement to maintain a constant draft. Where there is much difference in soil conditions, the draft control system could produce work of uneven depth, were it not for the regulator valve providing for an alteration in the rate of raising the implement in response to different soil conditions.

WITH AUTOMATIC POSITION CONTROL, any deviation of the implement from its preselected position causes ram arm *15* to turn accordingly. The corresponding position error signal is transmitted to the spool valve, much in the same way as in the case of automatic draft control, but now through the position control rod and arm, to move the implement back to its predetermined position. With the implement in this position, the position control rod and arm will have returned the spool valve to neutral. In this case, the bypass valve in the selector valve of the tractor hydraulic system is fully open, so that all of the oil delivered by the oil pump



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...strating the operation ... draft and/or position control and (b) sensing devices

... control mode selector lever;
... control lever;
... movable sleeve screw;
... expansion spring;
... movable sleeve;
... spool valve;
... spool valve nut;
... spool valve screw;
9 – position control arm;
10 – draft control arm;
11 – power cylinder lower chamber;
12 – draft control rod;
13 – position control rod;
14 – main power cylinder;
15 – ram arm (position sensing device);
16 – top link;
17 – bracket;
18 – draft sensing device;
19 – leaf spring;
20 – coil springs;
21 – ram rod;
22 – arm;
I – control unit;
II – main power cylinder;
III – hydraulic control valve;
IV – oil pump;
V – oil tank;
VI – hydraulic accumulator;
VII – traction control unit;
A, B, C, D, E, F, and G – hydraulic lines

returns to the oil tank, while oil is trapped in the lift chamber of the power cylinder by the spool valve closing the exit from the chamber. The implement is thus maintained in the desired position.

Control lever *2* of the draft and/or position control unit is placed into the "LIFT" position usually in order to lift the implement into the travel position at the end of run. In this case, the movable sleeve in the control unit covers the bypass valve control line *D*, and the oil delivered by the oil pump is directed to the lift chamber of the power cylinder via the following route: *IV–C–I–D–III–F–VII–G–A–II*. The oil contained in the lower chamber of the power cylinder is expelled into the oil tank through the body of control unit *I* and selector valve *III*.

After raising the implement, the driver releases the control lever. Once the lever is released, spring *4* in the control unit returns it to the "OFF" position. This is possible because the screws and nuts of the spool valve and movable sleeve are provided with multistart reversible worm threads.

WITH DEPTH CONTROL, the control lever of the draft and/or position control unit is latched on its quadrant in the "OFF" position. In this case, the unit has no effect on the hydraulic system, and the system is controlled by the selector valve and traction control unit.

Automatic draft control is employed when operating implements offering high draft resistance (e.g., plows) in fields with uniform soil conditions. Automatic position control finds application in operating farm machines offering high draft resistance (e.g., fertilizer distributors) in level fields.

16.7. Power Takeoff Shafts and Belt Pulley

THE POWER TAKEOFF SHAFT, usually called simply the power takeoff (abbreviated PTO, pto, or p.t.o.), provides a means to drive the machines that are being towed by the tractor. The engine power of the tractor is being used not only to pull or carry the machine, but also to operate it. Typical examples of machines that are power driven are mowers, balers, combines, potato harvesters, and manure spreaders. The PTO provides a very useful source of power, and the alternative would be to fit an engine to each of these machines. This is, of course, done where the power required to drive the machinery may be greater than the tractor can supply. Generally though, most farm machines can be powered by the tractor.

Power takeoff shafts are classified according to their location on the tractor, type of drive, rotational speed, and method of control.

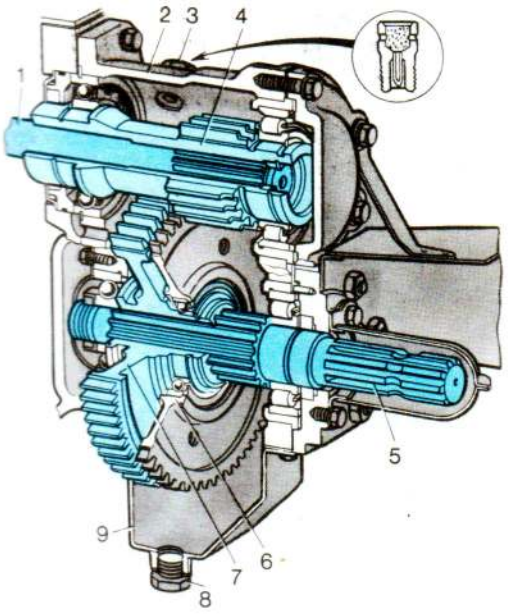
Most tractors are equipped with a rear PTO; some of them have a front PTO. Row-crop tractors use both a rear and a side PTO.

As to the type of drive, power takeoff shafts are classed as transmission drive, live (independent, or constant-running), semi-independent, and ground-speed types. *The transmission drive PTO* is driven from the tractor transmission, and so it will stop rotating whenever the engine clutch is disengaged. *The live PTO* is driven from the engine crankshaft through the clutch driving member irrespective of the position of the clutch (i.e., engaged or disengaged). *The semi-independent PTO* will continue to operate while the driver is shifting gears, but is incapable of being engaged or disengaged while the tractor is moving. *The ground-speed PTO* has its speed proportional to the ground speed of the tractor. Such a PTO finds application on row-crop tractors to operate machines, such as mounted drills, whose working rate must be in synchronism with the ground speed of the tractor.

The power takeoff speeds are standardized at 540 and 1000 rpm (at nominal engine speed). The splined ends of PTO shafts of all tractors are of one and the same size and are arranged at one and the same level relative to the tractor support surface. When the PTO shaft is not used, its end is covered by a guard stamped from sheet steel.

Power takeoff shafts may be controlled by either mechanical or hydraulic means.

PTO UNITS, OR ATTACHMENTS, WITH SIMPLE MECHANICAL CONTROL (Fig. 163) are usually of the transmission drive type. The unit is housed in case *2* and comprises a pair of spur gears



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PTO unit of ДТ-75М Model tractor

1 – drive shaft;
2 – PTO case;
3 – breather plug;
4 – drive gear;
5 – PTO shaft;
6 – oil splash gear;
7 – driven gear;
8 – oil drain plug;
9 – oil sump

Driven gear 7 can be slid along the splines on the internal end of PTO shaft *5* and into mesh with drive gear *4*. The engagement can only be effected when the tractor is stopped completely. Supported by a ball bearing on the hub of the driven gear is oil splash gear *6* whose purpose is to provide lubrication for the drive gear bearings when the PTO shaft is disengaged.

Live PTO shafts can be engaged and disengaged on the run by hydraulic or complex mechanical (planetary-gear) means.

THE PLANETARY-GEAR PTO UNIT (Fig. 164) consists of internal (ring) gear *12*, sun gear *10*, three planet gears *8* carried on planet carrier *11*, and two band brakes: planet carrier brake with drum *6* and sun gear brake with drum *7*.

The hub of the sun gear is rigidly attached to brake drum 7 which is freely supported by ball bearings on PTO shaft *4*. Brake drum *6* is rigidly fixed on shaft *4*. Steel brake bands *5* are equipped with friction linings. One end of each brake band is pivoted on a stationary pin, and the other end is connected through a bell crank and adjusting screws *2* to control shaft *1* operated by the PTO control lever.

When the PTO is disengaged (Fig. 165*a*), sun gear brake *5* is released and planet carrier brake *4* is applied. In this case, PTO shaft *3* is held stationary, and the planet gears transmit rotation from the internal gear to the sun gear.

When the PTO is engaged (Fig. 165*b*), sun gear brake *5* is applied and planet carrier brake *4* is released. The planet gears now have to walk around the sun gear. As the planet gears roll around the sun gear, they carry the planet carrier around with them, thus driving the PTO shaft which is rigidly connected to the planet carrier.

When the PTO is not used, the PTO control lever is placed into its neutral (central) position. In this case, both the sun gear and the planet carrier brakes are released.

Toothed clutch *1* inserted into the PTO drive line makes it possible to have either independent or ground-speed power takeoff. The clutch is operated by a control lever and can be placed into three different positions. When the clutch is shifted all the way forward (to the left, as shown in Fig. 165*a*), drive shaft *9* (see Fig. 164) of the PTO unit is connected to the transmission main (output) shaft to obtain ground-speed power takeoff. If the clutch is moved all the way backward (to the right, as shown in Fig. 165*b*), the drive shaft of the PTO unit will be connected to the engine crankshaft, and so power takeoff will be independent. With the clutch in its neutral (central) position, no drive is transmitted to the PTO unit.

To place the clutch into the «GROUND-SPEED PTO" position, one should disengage the engine clutch, whereas placing it into the "LIVE PTO" position requires that the engine should be stopped.

THE HYDRAULICALLY CONTROLLED PTO UNIT (Fig. 166) includes a planetary gear set and a self-contained hydraulic system. The unit

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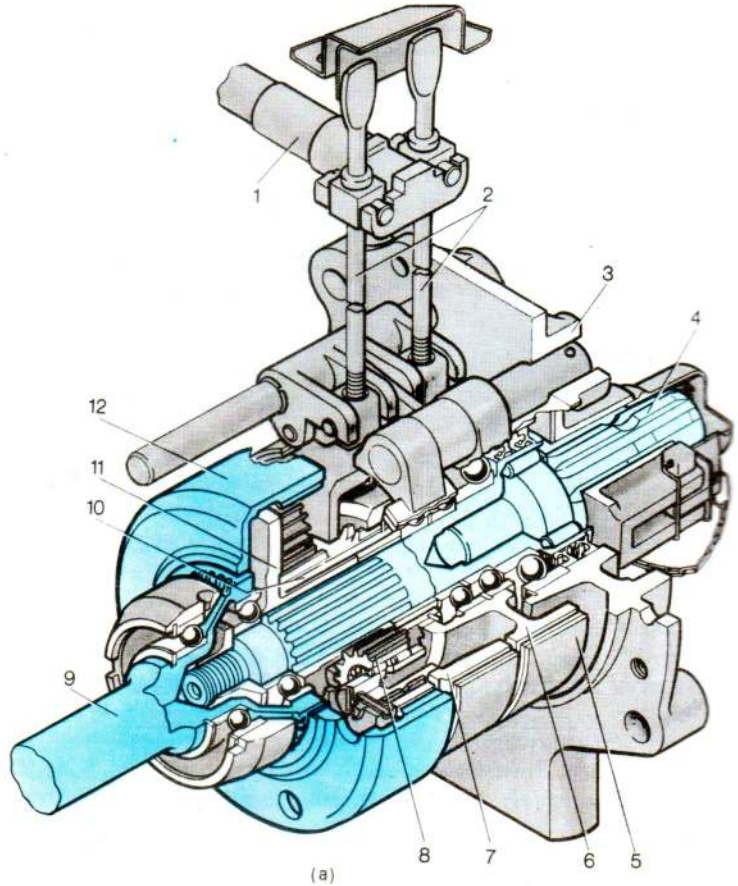
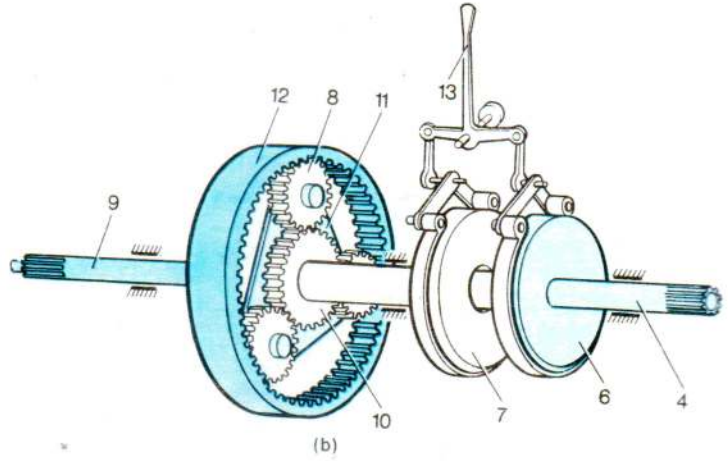
Planetary-gear PTO unit (MT3-80 Model tractor)

(a) construction;
(b) illustrating the principle of operation;
1 – control shaft;
2 – adjusting screws;
3 – rear cover;
4 – PTO shaft;
5 – brake band;
6 – planet carrier brake drum;
7 – sun gear brake drum;
8 – planet gear;
9 – drive shaft;
10 – sun gear;
11 – planet carrier;
12 – internal (ring) gear;
13 – PTO control lever



(a)



(b)

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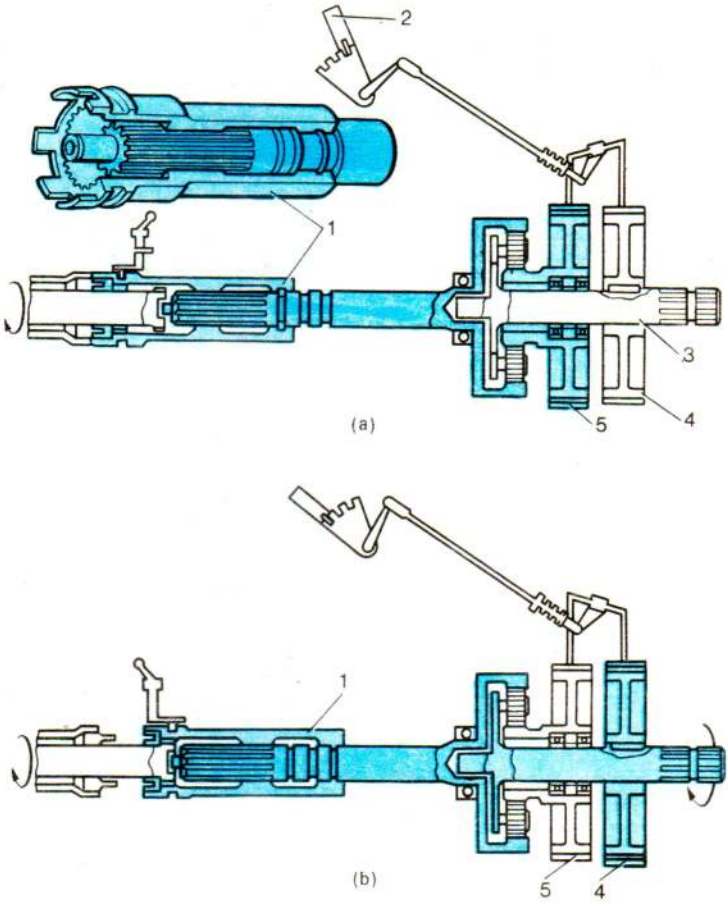
Illustrating the operation of the planetary-gear PTO unit

(a) PTO disengaged (ground-speed power takeoff); (b) PTO engaged (independent power takeoff); 1 – toothed clutch; 2 – PTO control lever; 3 – PTO shaft; 4 – planet carrier brake; 5 – sun gear brake

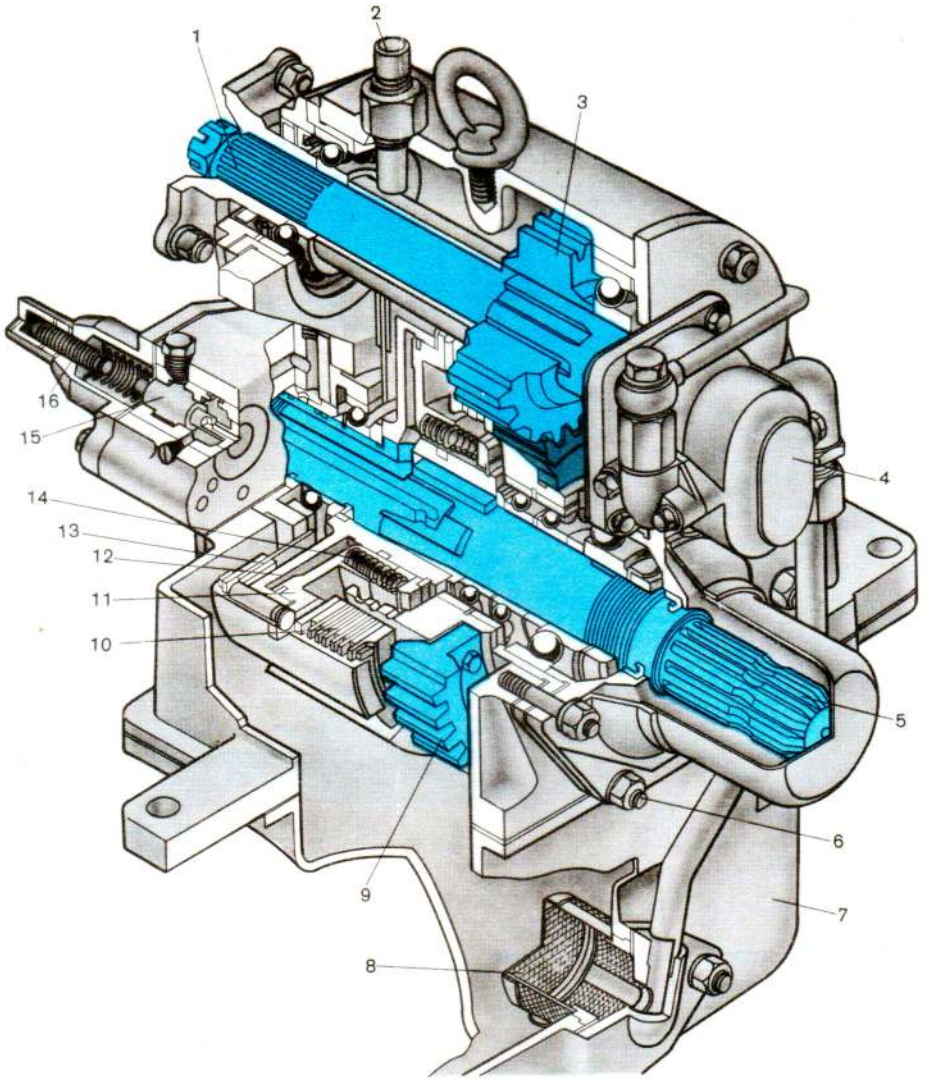


is contained in a case that is attached to the rear axle housing of the tractor.

The reduction gear set of the PTO unit comprises drive gear *3* carried on shaft *1* and driven gear *9* and hydraulic clutch *10* that are mounted on PTO shaft *5*. The shafts are supported by ball bearings housed in bores in the PTO case. Drive gear shaft *1* is driven from the engine crankshaft, and so the unit provides for independent power takeoff. The drive gear is splined to its shaft and is in constant mesh with the driven gear. The driven gear is fixed to a hub that is freely supported by ball bearings on the PTO shaft.

The connection between the driven gear and the PTO shaft is effected by hydraulic clutch *10* similar to those described in Section 11.4. The clutch comprises a series of driving and driven discs accommodated in a drum that is splined to the PTO shaft. The clutch driving discs are made of steel and equipped with cermet linings. These discs are splined on to the drive gear hub. The clutch driven discs of plain steel are arranged alternately between the driving discs and are splined into the clutch drum. Inside the clutch drum, there is annular space *12* that plays the part of a hydraulic cylinder, into which fits piston *11*. The piston is sealed in the annular space of the clutch drum by a cast-iron ring on the outside and a rubber ring on the inside and is loaded by a series of springs *14*.

To engage the clutch and hence the PTO



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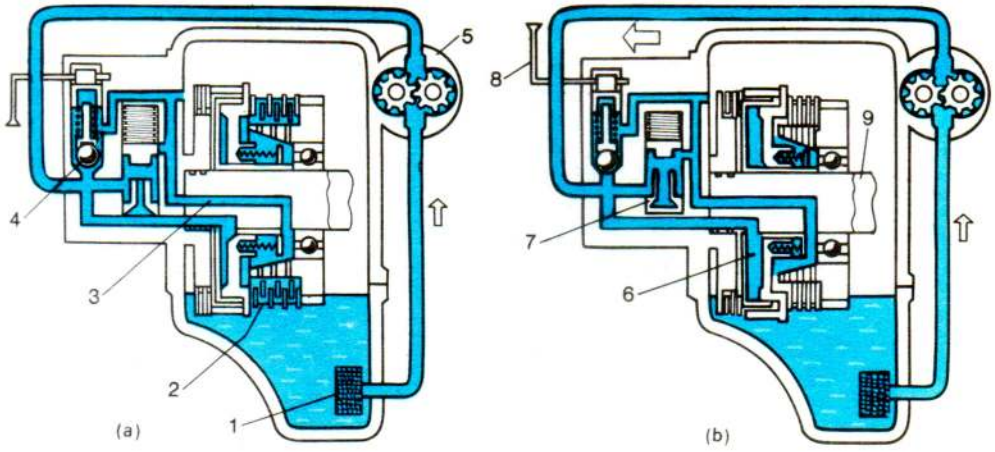
Hydraulically controlled PTO unit (T-150K Model tractor)

1 – drive gear shaft;
2 – breather plug;
3 – drive gear;
4 – oil pump;
5 – PTO shaft;
6 – overflow plug;
7 – oil sump;
8 – oil intake filter;
9 – driven gear;
10 – hydraulic clutch;
11 – piston;
12 – annular space;
13 – brake;
14 – release spring;
15 – pressure regulator valve;
16 – adjusting screw

shaft, oil is delivered under pressure into the annular space in the clutch drum. This causes the piston to move against spring pressure and tightly compress the pack of the clutch discs, thus connecting the PTO shaft to the driven gear of the reduction gear set. To disengage the clutch, the annular space in its drum is connected to a return line leading to oil sump. Now, release springs *14* force the piston to expel the oil contained in the annular space and



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Illustrating the operation of the hydraulic system of the hydraulically controlled PTO unit

(a) PTO disengaged;
(b) PTO engaged;
1 – oil intake filter;
2 – hydraulic clutch;
3 – oil passage;
4 – PTO control valve;
5 – oil pump;
6 – annular space;
7 – pressure regulator valve;
8 – PTO control lever;
9 – PTO shaft

release the clutch discs. The piston carries a series of pins which, at the end of the return stroke of the piston, bring pressure to bear against the disc of brake *13*, thus stropping the PTO shaft. Oil is let in and out of the clutch through passages drilled in the shaft.

The hydraulic system of the PTO unit includes oil pump *4*, oil intake filter *8*, a valve arrangement, and oil lines.

The valve arrangement includes pressure regulator valve *15* and PTO control valve *4* (Fig. 167) that are carried in a common housing bolted to the front wall of the PTO case.

The pressure regulator valve maintains a constant pressure (1 MPa) irrespective of the delivery of the oil pump.

The PTO control valve is essentially a ball valve loaded by two springs and operated by a plunger and an eccentric held to the shaft of PTO control lever *8*. When the PTO shaft is engaged, the control valve also doubles as a relief valve.

With PTO control lever in the "OFF" position (Fig. 167*a*), the eccentric on the control lever shaft releases the control valve plunger, which relieves the ball valve of spring pressure. In this case, oil pump *5* draws oil from the oil sump of the PTO case through oil intake filter *1* and delivers via the discharge line to both valves of the valve arrangement. Since PTO control valve *4* is relieved of spring pressure, the oil flows past it and returns to the sump, some oil going through passage *3* drilled in the PTO shaft to lubricate the friction discs of hydraulic clutch *2*.

When the PTO control lever is placed into the "ON" position (Fig. 167*b*), the eccentric turns and depresses the control valve plunger. As the plunger is depressed, it compresses both control valve springs which, in turn, push the valve against its seat. This closes the oil return passage to the sump. Since there is no escape route open to the oil, the pressure in the system goes up, and the oil is forced into annular space *6* of the clutch and causes the clutch piston to press together the clutch discs and thus engage the PTO shaft. The oil pressure will rise to 1 MPa, at which point pressure regulator valve *7* will come into operation to maintain this pressure invariable. To make the clutch engage smoothly, the PTO control lever should be operated slowly.

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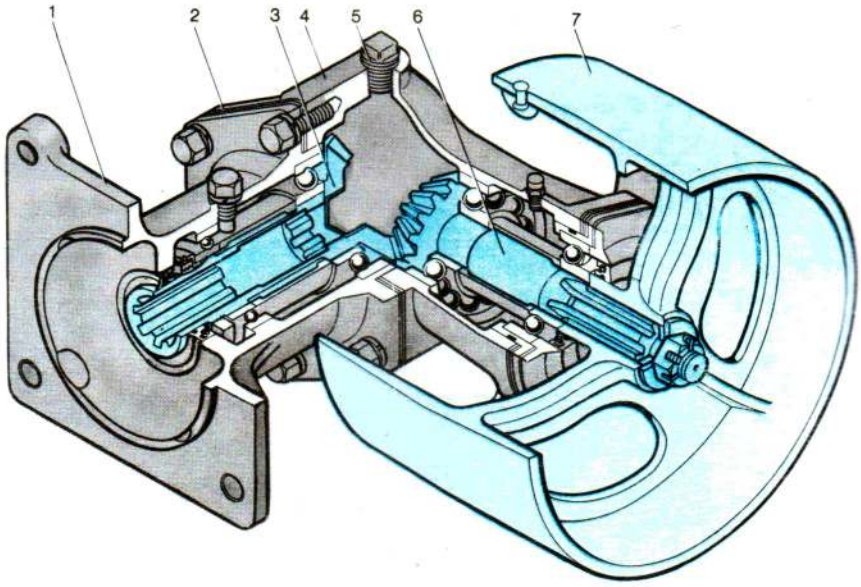
Belt pulley unit

1 – sleeve;
2 – adjusting shims;
3 – drive gear;
4 – case;
5 – filler plug;
6 – driven gear;
7 – belt pulley



THE BELT PULLEY UNIT (Fig. 168) serves to drive various stationary farm machines by a flat belt. The pulley unit usually fits over the PTO shaft at the rear of the tractor and uses the normal PTO control levers and clutches. The belt pulley axis must be at right angles to the centerline of the tractor in order to enable one to align and tighten the drive belt properly by moving the tractor relative to the driven equipment.

The belt pulley unit is essentially a bevel reduction gear comprising a pair of miter gears *3* and *6* housed in case *4* with sleeve *1*. Drive gear *3* is supported by ball bearings in sleeve *1* and fits over the splined end of the PTO shaft. Driven gear *6* is made integral with its shaft that is supported by two ball bearings in case *4*. The driven gear shaft protrudes outside the belt pulley case and carries belt pulley *7* that is splined to its end. The belt pulley is held fast to the driven gear shaft by a nut. The backlash between the gears is adjusted by means of shims placed under the flange of the housing for the driven gear outer bearing and also between the mating flanges of the belt pulley case and sleeve.

The component parts of the belt pulley unit are splash lubricated with transmission oil contained in the case. The case is filled with oil through the hole closed by plug *5*. The proper oil level is established by means of an overflow hole provided in the case.

On tractors equipped with a transverse-shaft transmission, the belt pulley unit is attached to a side wall of the transmission case.

16.8. Working Attachments Troubles

Generally, most tractor working attachments troubles originate in the hydraulic system. For the system to operate without giving any troubles, it is essential that the oil used should be clean and the system should be free from air leaks. When changing oil in the hydraulic system, absolute cleanliness should be aimed at. Not a single hydraulic line connection should be permitted to work loose.

A list of possible working attachments troubles is as follows. The mounted implement fails to lift or lifts too slowly; it lowers suddenly when the hydraulic control lever is placed into the "FLOAT" position, fails to stay in the travel position, or produces work of uneven depth. Oil gets overheated, or it foams in the oil tank

and is thrown out of it through the breather. Hydraulic traction booster fails to help in reducing the slipping of the rear wheels of the tractor. Hydraulic control levers fail to return to neutral. Draft and/or position control lever fails to return to the "OFF" position after lifting the implement into the travel position, or fails to latch in the "OFF" position on its quadrant. Noisy PTO or belt pulley unit.

Failure of the mounted implement to lift may be due to various causes. The swivel nut of some hydraulic hose connection may work loose, with the result that the shutoff valves in the connectors will prevent the passage of oil to the power cylinder. The hydraulic control valve may have its control spool stuck in the "LOWER" position or its bypass valve stuck in the open position. To correct the trouble, check for loose hydraulic hose connections and tighten loose swivel nuts, if any. A stuck control spool can be freed by placing the hydraulic control lever into the "LOWER" position and then shifting it quickly to the "LIFT" position. A stuck bypass valve should be removed, washed clean, and installed in place.

If the implement fails to lift when operating the hydraulic control lever, but does so when operating the draft and/or position control lever, the remedy is to adjust the position of the draft and/or position control lever quadrant on its support bracket.

Slow lifting of the implement may be due to air in the hydraulic system or excessive slipping of the oil pump. Air leaks should be eliminated, and an oil pump having insufficient delivery should be replaced.

The implement may lower too fast because of the restrictor valve installed in a wrong place or absent altogether. The restrictor valve fitting should be screwed in the power cylinder inlet port communicating with the lift chamber.

Failure of the implement to stay in the travel position is due to the oil escaping from the power cylinder. This may be caused by worn sealing rings of the piston or piston rod, a poorly fitting check valve in the traction control unit, or worn control spools or their holes in the hydraulic control valve. Worn sealing components should be replaced. The check valve of the traction control unit should be made to fit its seat tightly. A hydraulic control valve having its control spools too loose in their holes should be replaced.

Uneven depth of work may be due to incorrect adjustment of the hitch linkage. Should it prove to be the case, level the implement by properly adjusting the length of the top link and the right-hand lift link. If the implement produces work of uneven depth when it is being operated without making use of the automatic draft or position control, place the hydraulic control lever into the "FLOAT" position and reduce the uplift pressure in the power cylinder by turning counterclockwise the handwheel of the traction control unit.

Oil in the hydraulic system may get overheated because of its level in the oil tank staying too low. Crushed metal hydraulic lines may also be the cause of this trouble. The oil tank should be filled to the level of the top mark on the dipstick. Crushed hydraulic lines should be repaired or replaced.

Oil will foam in the oil tank and will be thrown out of it through the breather if air enters the hydraulic system through leaky joints in the inlet line or past worn shaft seals of the oil pump. To correct the trouble, tighten all the joints in the inlet line and replace damaged sealing gaskets and worn shaft seals.

If the hydraulic traction booster fails to help in reducing the slipping of the rear wheels, the trouble is probably caused by incorrect adjustment of the main power cylinder control rod in the selector valve or some internal trouble in the traction control unit, such as a stuck valve. To correct the trouble, check and adjust, if necessary, the length of the control rod. Should it prove to be no help, remove the traction control unit, disassemble it, and wash clean all its component parts.

Failure of hydraulic control levers to return automatically to neutral is most probably caused by incorrect adjustment of the relief valve and control spool release valves in the hydraulic selector.

The draft and/or position control lever will not latch in the "OFF" position if the latch spring is incorrectly adjusted or if the lever or

its quadrant is damaged. The latch spring should be adjusted so as to allow the lever to be moved without its getting stuck on the quadrant and latched securely in the "OFF" position. Any bends or dents in the lever or its quadrant should be straightened.

A noisy PTO or belt pulley unit points to excessive wear of gears or bearings or excessive backlash between the gears. Worn components should be replaced and the backlash between gears adjusted properly.

Review Questions

1. What is known as the tractor working attachments?
2. List the units making up the tractor hydraulic system.
3. Referring to Fig. 149, show the route of oil in the tractor hydraulic system when lifting an implement mounted on the tractor.
4. What is the purpose of the hydraulic hose connections?
5. What is the purpose of the adjustable stop on the piston rod of the power cylinder?
6. What is the purpose of the restrictor valve in the power cylinder?
7. How is the automatic return of the control spools in the hydraulic control valve effected?
8. What is the difference between the two- and three-point hitch linkages?
9. How can the point of attachment of the top link to the tractor be changed?
10. What is the purpose of the hydraulic hook and belt pulley?
11. Explain the principle of operation of the mechanical and hydraulic traction boosters.
12. Where are the automatic draft and position control systems used?
13. What are the draft and position sensing devices?
14. What is the advantage of live power takeoff?
15. An implement mounted on the tractor fails to lift. What are the possible causes of the trouble?
16. How can one eliminate the foaming of oil in the oil tank of the tractor hydraulic system?

Chapter 17
Auxiliary Equipment and Trailers

17.1. Auxiliary Equipment

Automotive auxiliary equipment serves the purpose of improving the conditions of driver's work, so as to allow the driver to perform many complex tasks with efficiency, safety, and a minimum of fatigue. Such equipment includes the driver's cab, together with the engine hood and front splash panelling, various hitch devices, winches, etc.

Row-crop tractors are equipped with one-seater cabs, while general-purpose tractors and automobiles usually use two- or three-seater cabs of all-metal construction. As an example, consider the construction of a general-purpose tractor cab (Fig. 169).

On the outside, the cab is coated with a layer of sound-insulating mastic *2* covered with a layer of pasteboard *1*, and on the inside, it is finished in wateproof pasteboard *3*. To reduce the adverse effect of vibrations on the driver, the cab is held to the tractor frame by four isolation mounts *8* of rubber. The construction of the cab provides for good visibility. Front windows *4* are hinged, so that they can be opened for ventilation purposes. The door glasses are equipped with regulators (window raisers) *5*.

In cold weather, the cab is heated with warm air supplied from the radiator via a metal duct. Some of the air is directed onto the front glasses (windscreens) for defrosting purposes, and the rest is ducted into the cab interior through an outlet arranged under the instrument panel. The air outlet is equipped with a shutter that can be closed to direct all of the warm air entering the cab onto the front glasses. In summer time, the air inlet to the cab (which is located under the engine hood) is closed with another shutter, and the air scoop is removed together with the metal air duct.

The cab is force-ventilated by means of a fan

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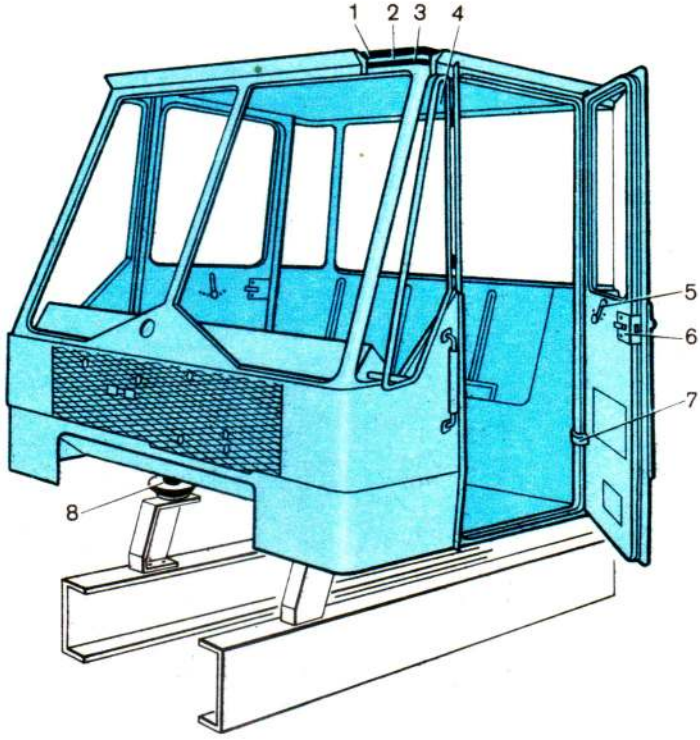
Driver's cab of T-150K Model tractor

1 – sound-insulating pasteboard;
2 – sound-insulating mastic;
3 – waterproof pasteboard;
4 – front windows;
5 – door glass regulator (window raiser);
6 – door lock;
7 – door check;
8 – cab isolation mount



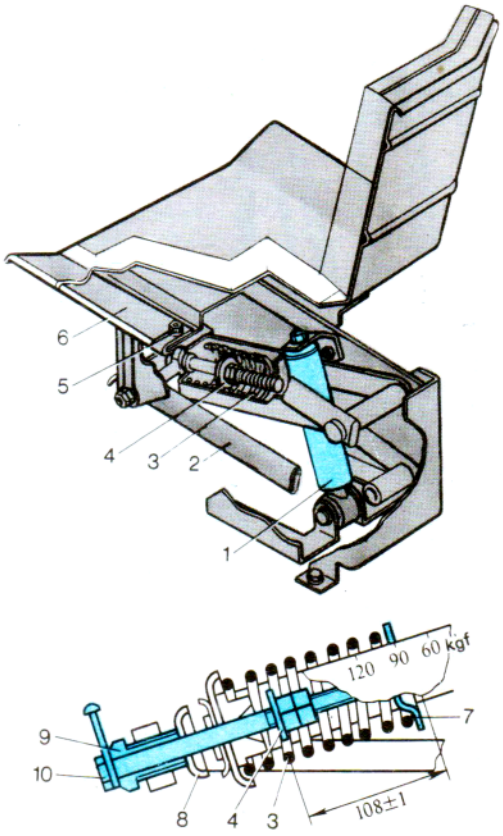
mounted on the cab roof. The fan is equipped with a dust separator to clean the air forced into the cab. A deflector plate is used in the air outlet in the cab to allow the direction of the air stream to be changed. An optional fan may be installed inside the cab. The fan motor switches are mounted on the instrument panel.

The cab is equipped with a sun visor, a rear-view mirror, thermos bottle for drinking water, a first aid kit, and two coat hooks. Provision is made for mounting a fire extinguisher on the outside of the right side panel of the cab. There are also glass cleaners for both the front and the rear glasses. The front glass cleaner is electrically driven, while the rear one is operated by hand. The tractor is provided with running boards and mounting steps to make it easier for the driver to climb into the cab and to fill the radiator with water.

Accommodated in the tractor cab are two seats: a driver's seat and a passenger's seat.

THE DRIVER'S SEAT (Fig. 170) has a parallelogram-type suspension incorporating spring *3* and hydraulic damper (shock absorber) *1*. The seat can be adjusted to suit both the mass and stature of the driver. The passenger's seat is unsprung and non-adjustable. Both seats have foam padded cushions and backrests. The passenger's seat backrest is detachable. The cab may be equipped with an optional spring-mounted passenger's seat.

THE ENGINE HOOD AND FRONT SPLASH PANELLING (Fig. 171) protect the engine and other mechanisms of the tractor from atmospheric precipitation and dirt. The hood and front splash panelling elements include detachable radiator screens *2*, radiator shell *3*,



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Sprung seat

1 – hydraulic damper (shock absorber);
2 – suspension link;
3 – spring;
4 – special washer;
5 – bolt;
6 – guide;
7 – rear spring seat;
8 – rubber thrust block;
9 – adjusting sleeve;
10 – adjusting bolt

hood top *5*, hinged hood side panels *6*, hood back panel *7*, mud shields *9* with quick-detachable extension shields *8*, and fenders *10* that protect the tractor against splashing.

In summer (at ambient temperatures above 20°C), the extension shields should be removed to enable the engine to run cooler.

Access to the radiator filler cap is gained through door *4* provided in the radiator shell.

The hood side panel catches are designed so as to keep the panels in the raised position. (Note. Driving the tractor with the hood side panels raised is not allowed).

The cab may be equipped with an air conditioner to provide for the diver's thermal comfort.

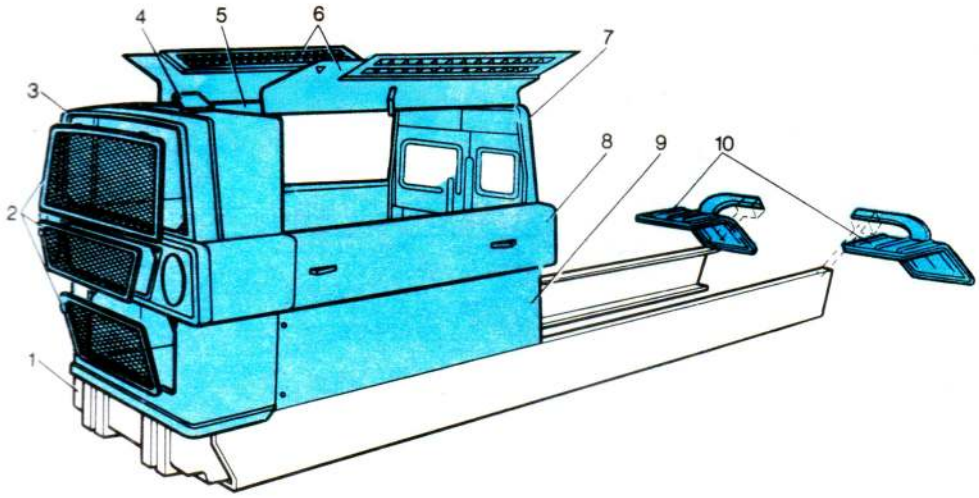
Auxiliary equipment of trucks includes, in addition to the cab, hood, fenders, etc. that are very much like those described above, also a towing gear equipped with a cushion spring whose purpose is to cushion jerks occurring when starting away from rest with a trailer or a vehicle attached to the truck. Tractor semitrailers, i.e., tractor trucks specially designed for handling semitrailers, are equipped with a self-acting trailer coupling. known as the fifth wheel assembly, which enables the semitrailer to be automatically hitched to the tractor truck and excludes the possibility of the semitrailer breaking loose from the truck. The hitching of the semitrailer involves reversing the tractor truck slowly under the braked semitrailer until the hitch jaws of the fifth wheel assembly lock on the coupling pin of the semitrailer.

THE FIFTH WHEEL ASSEMBLY (Fig. 172) consists of base plate *2*, fifth wheel *3*, and rocker *12*. The base plate is fixed on the frame of the tractor truck, and the fifth wheel is held to the rocker that is pivoted on the base plate. The fifth wheel carries a hitch device comprising hitch jaws *8* and *10* that serve to couple the tractor truck to the semitrailer. When the semitrailer is hitched to the tractor truck. locking bar *9*, loaded by spring *7*, keeps the hitch jaws in the locked position.

To unhitch the semitrailer, lever *11* is turned to move locking bar *9* forward. This releases the hitch jaws, so that the coupling pin of the semitrailer can freely disengage from them.

THE WINCH (Fig. 173) is mounted at the front of some cross-country trucks. It serves for lifting various weights, hauling out stalled vehicles, or for self-recovery. The winch consists of a reduction gear, a drum, and a drive.

The reduction gear comprises worm *7* and worm wheel *6*. The worm is supported by taper



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Engine hood and front splash panelling of T-150K Model tractor

1 – frame;
2 – radiator screens;
3 – radiator shell;
4 – radiator filler cap access door;
5 – hood top;
6 – hood side panels;
7 – hood back panel;
8 – extension mud shield;
9 – mud shield;
10 – fenders

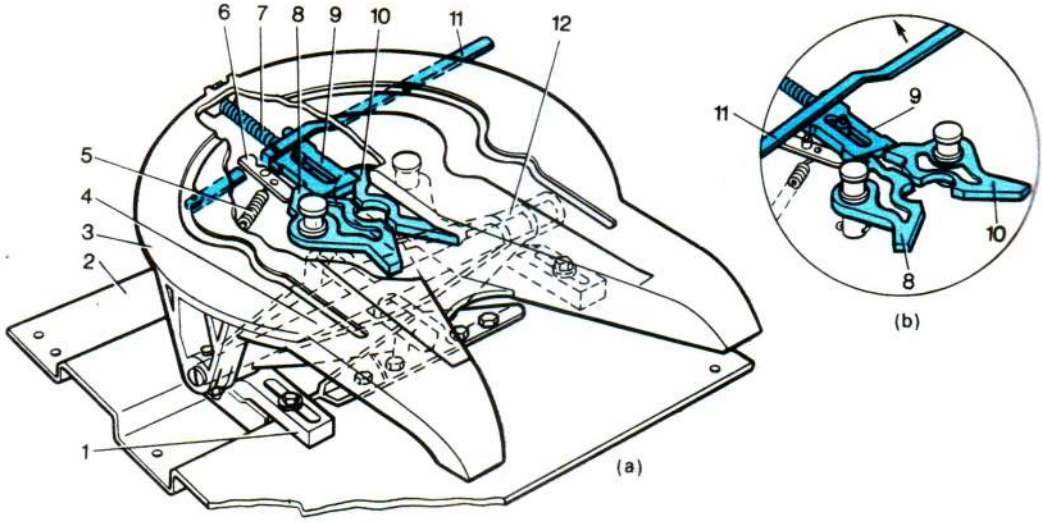
roller bearings carried in bores in the reduction gear housing that are closed by covers. The worm wheel is keyed to shaft *3* which carries winch drum *2* with a wire cable wound around it. The winch drum is free to rotate on the shaft and can be connected to it by means of a sliding dog coupling splined on to the shaft. To engage the winch drum, the coupling is slid along the shaft until the coupling dogs mate with identical dogs on the end face of the drum hub. This is done by operating winch lever *4*. The lever is provided with a latch, so that the winch coupling can be locked in both engaged and disengaged positions. When the winch coupling is engaged, it transmits the drive from shaft *3* to the winch drum. With the winch drum rotating, the cable is wound upon the drum and hoists or hauls the weight or vehicle attached to its end.

The winch is driven from the transmission of the truck via transfer case *1* and universal-joint drive *8* connected to worm *7* of the winch reduction gear. The transfer case has two forward and one reverse speed ratios and a neutral in between. The transfer case gears are shifted by means of a lever arranged in the driver's cab. To put the winch into operation, the transmission control lever is placed in neutral, the winch coupling is engaged and then the clutch is disengaged and the transfer case is put into the desired gear. After that, the clutch is smoothly let in and the engine is revved up. To stop the winch drum, the clutch pedal is depressed and the transfer case control lever is placed in neutral.

Mounted on the internal end of the worm shaft is the pulley of band brake *5* which is applied automatically in case the cable should start unwinding from the winch drum too fast. This would be the case if the shear pin provided in the front universal-joint fork should break as a result of the load on the cable growing in excess of the permissible value.

17.2. Trailers and Body Tipping Mechanism

Tractor and automobile trailers are classed according to the manner in which they transmit load onto their support surface.



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Fifth wheel assembly

(a) construction;
(b) illustrating the moment of unhitching;
1 – stop;
2 – base plate;
3 – fifth wheel;
4 – rocker shaft;
5 – latch spring;
6 – latch;
7 – locking bar spring;
8 – left-hand hitch jaw;
9 – locking bar;
10 – right-hand hitch jaw;
11 – release lever;
12 – rocker

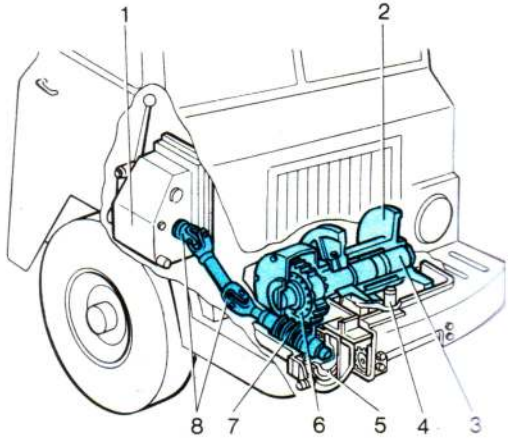
A full trailer is a truck whose wheels fully support the vertical load due to its own weight and the weight of the cargo it carries.

A semitrailer is a trailer whose front end is supported by the tractor in such a way that some of the vertical load is transmitted to the rear wheels of the tractor.

Trailers may be of two-wheeled, four-wheeled, and multi-wheel type, i.e., they may have one, two, and more axles.

A trailer consists of a frame, a body, one or more axles, wheels, and a coupling. The frame of the trailer is supported on its axles and wheels by springs. The trailer coupling is attached to the front part of the frame. The coupling may be either of rigid or of cushion-spring type.

Trailers having more than one axle may be equipped with a swivelling device. It consists of



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Winch

1 – transfer case;
2 – winch drum;
3 – worm wheel shaft;
4 – winch lever;
5 – automatic winch brake
6 – worm wheel;
7 – worm;
8 – universal-joint drive

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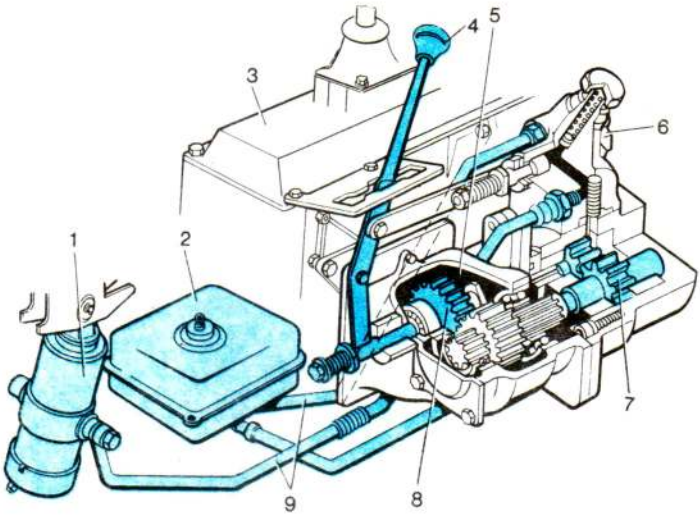
Body tipping mechanism of a dump truck

1 – power (telescopic) cylinder;
2 – oil tank;
3 – truck transmission case;
4 – tipper control lever;
5 – transfer case;
6 – hydraulic control valve;
7 – oil pump;
8 – transfer case idler gear;
9 – hydraulic lines



two ring-shaped swivel blocks with a series of rollers or balls placed between them, which enable the front axle of the trailer to be readily turned relative to the frame. In this case, the front part of the frame is supported by its swivel block on the swivel block of the subframe.

Semitrailers may have one or several axles at the rear and may be equipped with jockey wheels to support their front end whenever they are unhitched from their tractors. Fifth wheel trailers require no swivelling device, its function being performed by the fifth wheel assembly of the tractor.

All trailers are equipped with brakes, marker lights, turn-indicator lights, and stop lights. All the necessary hydraulic, pneumatic, and electrical connections between the tractors and the trailers are effected by means of breakaway connection devices.

The trucking of bulk freight can be made more effective by utilizing motor trucks and tractor-trailer combinations equipped with dump bodies. Generally, these are of the rear-dump type, but side, two-way, and three-way dump bodies also find application. Dump trucks and trailers are equipped with a special mechanism to tip their bodies and thus dump the contents.

THE BODY TIPPING MECHANISM (Fig. 174) of a motor truck consists of power (telescopic) cylinder *1*, gear-type oil pump *7*, oil tank *2*, hydraulic control valve *6* operated by control lever *4*, transfer case *5*, and hydraulic lines *9*.

The body is tipped by the power cylinder which extends under the pressure of oil forced by the oil pump into the cylinder space under the ram (piston) and lifts the front end of the body (in rear-dump trucks). The body returns to its horizontal position under its own weight, the oil contained in the cylinder being expelled into the oil tank by the ram.

The oil pump is attached to the transfer case which in this case has a single speed ratio. By operating tipper control lever *4*, transfer case idler gear *8* can be slid along its shaft to mesh the reverse gear in truck transmission case *3* with the oil pump driving gear in transfer case *5* and thus engage the oil pump.

The power cylinder is controlled by means of a hydraulic control valve that is operated by the same tipper control lever *4*. The hydraulic control valve is designed so that the dump body not only can be lifted (tipped) and lowered, but can also be held in any intermediate position. It consists of a control spool, a check valve, and a relief valve.

Pulling back on the tipper control lever (to the left in Fig. 174) causes idler gear *8* to move forward and engage the oil pump. At the same time, this causes the control spool that is

connected to the lever to move backward to connect the discharge chamber of the oil pump to the power cylinder through the check valve. The oil forced by the pump pushes the check valve off its seat and goes to the cylinder. This causes the cylinder to extend and tip the dump body of the truck.

To hold the body in the fully tipped position or in any intermediate position, the tipper control lever is placed in its neutral (central) position. This action disengages the oil pump. Now, the weight of the dump body brings pressure to bear on the check valve from the wrong direction. The check valve is thus forced to close and trap oil in the cylinder, which prevents any movement of the dump body.

Pushing the tipper control lever fully forward causes the control spool to connect the power cylinder to the return oil line leading to the oil tank. The weight of the dump body now causes the power cylinder to retract. The ram forces the oil out of the cylinder and into the tank, and the dump body slowly lowers into the horizontal position.

Once the power cylinder reaches its extreme position on the extension stroke, the oil pressure in the system starts rising. This causes the relief valve to open and connect the discharge chamber of the pump to the oil return line, unless the driver places the tipper control lever in neutral in due time.

Review Questions

1. How is the driver's cab of a modern tractor constructed?
2. What is the difference between the driver's seat and the passenger's seat?
3. What is the advantage of the fifth wheel assembly of a tractor truck?
4. What is the purpose of the winch?
5. What is the safety device used in the winch in case the load on the cable should exceed the permissible value?
6. What is the difference between the full trailer and semitrailer?
7. Referring to Fig. 174, explain the operation of the body tipping mechanism of a dump truck.

Part IV
AUTOMOTIVE ELECTRICAL EQUIPMENT

Electricity is one of the forms of energy that are widely used in modern tractors and automobiles. While studying the material contained in this part of the book, you will get familiar with the physical phenomena that find application in automotive electrical equipment.

In tractors and automobiles, electricity does several jobs. It starts the engine (where starter motors are used), ignites the compressed air-fuel mixture (in carburettor engines), and operates sound and light signalling devices, the lights, electric gauges, and all sorts of auxiliary equipment.

Devices that supply electrical energy are referred to as *power supply sources*, or simply power supplies, whereas those consuming electrical energy are called *loads*, or using equipment. The power supply sources used on tractors and automobiles are the battery and the generator (alternator). The loads include the starter (cranking) motor, the ignition coil, signalling devices, the lights, electric gauges, and auxiliaries.

The power supply sources mentioned above convert chemical energy (the battery) and mechanical energy (the generator) into electrical energy, and the loads serve to convert electrical energy into other forms of energy, such as mechanical, light (luminous), sound (acoustic), and heat (thermal) energy.

Chapter 18
Power Supply Sources

18.1. Electricity and Magnetism

ELECTRON THEORY. All matter is composed of small parts called molecules. These molecules are made up of two or more atoms. Fortunately, most materials of interest electrically have simple molecular structures consisting of only one or two atoms.

The atom consists of a positively charged nucleus surrounded by one or more negatively charged electrons. The nucleus is composed of two different types of elementary particles – the proton which is positively charged, and the neutron which is electrically neutral. The charge of the electron is numerically equal to that of the proton, but is opposite in sign. The number of electrons in the electrically neutral atom is therefore equal to the number of protons in the nucleus.

The electrons move about the nucleus in orbits in the same sense that the planets orbit about the sun. The motion of the planets about the sun takes place essentially in a plane, whereas the orbital paths of the electrons follow concentric three-dimensional spherical surfaces, called electron shells, rather than the planar paths of the planets.

Electron shells are arranged at various, but well defined, distances from the nucleus, and the number of electrons in each shell is restricted. The outer electron shell is frequently referred to as the valence shell, meaning that the number of electrons in the outer shell of an atom determines its valence. Such an explanation of valence is based on the assumption that certain arrangements of outer electrons in atoms, for example, octets or outer shells of 8 electrons, are stable and tend to be formed by the transfer of electrons from one atom to another.

The nucleus keeps the electrons in orbits around itself by the force of attraction between the charges on the electrons and the charge on the nucleus. The electrons which are closer to the nucleus are more strongly attracted to it

than the electrons which are farther away. The electrons in the outer shell are partially free from the pull, and therefore can sometimes be forced off their orbit. They are called free electrons. Those in the inner shells are called bonded electrons.

Normally, the atom is electrically neutral. If a state of imbalance should develop through the loss of electrons, the atom becomes positive in charge. It then tends to attract other electrons in order to regain its balance. This electrical imbalance (potential difference) is the basic principle underlying electric current, for imbalance causes electrons to flow from atom to atom.

CONDUCTORS. A conductor may be defined as matter made up of atoms whose free electrons are dislodged easily and whose orbits overlap, allowing easy electron flow from atom to atom. Such atoms have an atomic structure of less than four electrons in their valence (outer) shell. The atoms of most metals have one, two, or three electrons in their outer shell, and so they are good conductors.

The atomic structure governs the conductivity of an element, or the extent to which it resists the movement of electrons. Elements such as silver, copper, or aluminium are good electron carriers because their free electrons are not very closely tied to the atom. Copper is presently the most common carrier of current (electrons) because it is comercially economical, bends easily, and offers little change in resistance with changes in temperature.

There are two other factors in addition to temperature which can change the resistance of a conductor. They are the cross-sectional area and the length. As the cross-sectional area is increased, the electron-carrying capacity increases because there are more atoms available to carry the current, and so the resistance is reduced. When a conductor is lengthened without increasing its cross-sectional area, more electrons have to be dislodged. This causes heat and increases resistance.

Some nonmetallic elements such as carbon are also good conductors. So are aqueous solutions of salts, alkalis, and acids, but the mechanism of conduction in such solutions differs from that in solid conductors.

Tractors and automobiles use copper and aluminium conductors (wires) to interconnect the various components or their electrical systems.

INSULATORS (NONCONDUCTORS). An insulator is composed of one or more atoms with an atomic structure of more than four electrons in the outer shell. The structure will not allow the movement of electrons because there are no free electrons present. The most common insulators used for electrical wiring are natural and synthetic rubber, plastics, varnishes, mica, and various fibers.

Insulators are essential to the conductors of any electrical device, for they prevent electron losses, short or grounded circuits, and can separate two conductors. They also protect the conductors from external damage, oil, dirt, water, and heat.

SEMICONDUCTORS. Semiconductor materials (elements) are neither good conductors nor good insulators because they are materials which have an atomic structure of three or five electrons in the outer shell. However, these materials can be altered to fulfill a useful purpose, that is, to act as an electrical device which can act as a conductor under certain conditions and as a nonconductor under other conditions. (Note. More information on semiconductors will be given later in the text in connection with semiconductor devices).

RESISTANCE. Resistance is any force tending to hinder motion. Each atom resists the removal of its free electrons due to attraction of the nucleus. Resistance in a conductor, semiconductor, or insulator is the opposing force which the atoms give to the movement of electrons. The unit of resistance is the ohm (Ω).

ELECTRON FLOW. Electrons will flow from atom to atom when there is a path which connects the concentration of electrons on the negative terminal of a power supply source with the positive terminal, which lacks electrons. When the terminals are connected by a conductor, an electric circuit is made and the free electrons will flow from atom to atom, hence from terminal to terminal, at a speed of 344,472 kilometers per second. However, it has

been proven scientifically that they travel only a few centimeters per minute in the conductor.

CURRENT FLOW.There are two theories, the conventional theory and the electron theory. The conventional theory states that current flows from the positive terminal (designated by the + sign) of the power supply source to the negative terminal (−) of the source. The electron theory states that free electrons flow from negative to positive. Accordingly, we are faced with "two kinds of current". One is the conventional current, and the other is the electron current. The rate of flow of electrons is called electric current. The unit of electric current is the ampere (A) and represents a flow of one coulomb (6.242×10^{18} electrons) through a given cross section of a conductor in one second. The way to measure this flow is by using an ammeter. Regardless of whether the electrons move from + to − or from − to +, they have to pass the ammeter which measures the flow in amperes.

DIRECT CURRENT AND ALTERNATING CURRENT. The term "direct current" refers to the flow of electrons in one direction only. This means that the power supply source does not change its polarity. When the flow of electrons reverses direction continuously, it is called alternating current. All the loads (using equipment) in the electrical systems of tractors and automobiles operate on direct current. However, some automotive power supply sources, namely, the alternators, produce alternating current, and so their output has to be inverted (rectified) before it can be used to supply the using equipment.

VOLTAGE (ELECTROMOTIVE FORCE). Voltage is the difference in the concentration of electrons between the negative and positive terminals of a power supply source. When the two points of different potential are connected, the potential difference between these two points causes the electrons to move because of their forces of attraction and repulsion. The potential difference is called voltage or electromotive force (emf), and the unit of measurement is the volt (V). The greater the concentration of electrons at one terminal, the greater will be the voltage or potential energy to do work. The voltage in automotive electrical systems is equal to 12 V.

POWER. The work done, or energy expended, by electric current in a unit time is called power, and the unit of measurement is the watt (W). The power in watts is given by the product of the current in amperes and the voltage (potential difference) in volts.

OHM'S LAW. Ohm's law states that the intensity of the electric current in a circuit is proportional to the voltage (emf) and inversely proportional to the resistance. In other words, the current flow can be changed by changing the voltage or by changing the resistance in the circuit. Note, however, that current has no effect on resistance or voltage, but each has an effect on current.

ELECTRIC CIRCUITS. An electric circuit is basically a path for current flow. It includes a power supply source, a load (resistor, such as an electric motor or a light bulb), and conductors (wires) which form the path for the current.

Electric circuits are classified according to the manner in which the electrical components (power supply sources and loads) are connected to form the circuit.

When several power supply sources are connected in series (Fig. 175*a*), the positive terminal, for example, of one source is connected to the negative terminal of the next one, and the positive terminal of the latter is connected to the negative terminal of the third, and so on. In this case, the total voltage across the negative terminal of the first source and the positive terminal of the last one will be equal to the sum of the voltages of all individual sources. For instance, if the voltage of a single lead-acid battery element or cell is 2V, six such elements must be connected in series in order to obtain a total voltage of 12 V.

With the parallel connection of several power supply sources (Fig. 175*b*), the like terminals of all individual sources are connected together. The total voltage in this case will be the same as the voltage of a single source, but the total capacity (amount of current that a battery can deliver) will be equal to the sum of capacities of all individual sources. (In our example, the total

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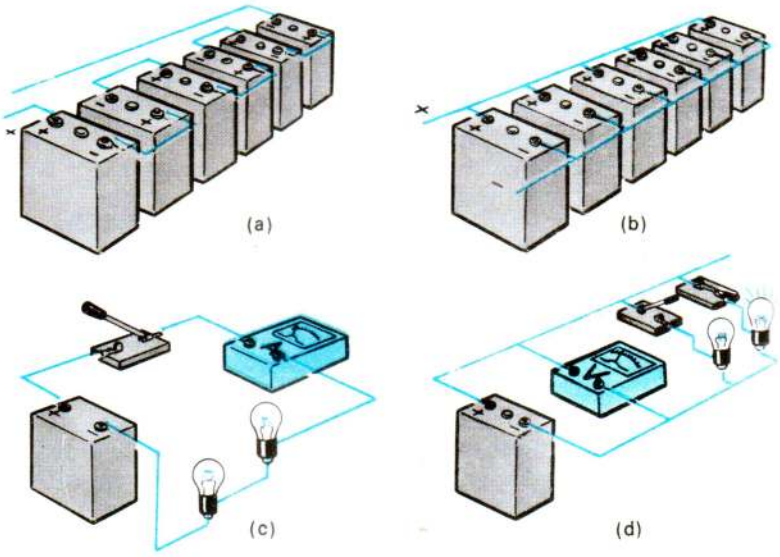
Types of electrical connections

(a) series connection of power supply sources; (b) parallel connection of power supply sources; (c) series connection of loads (using equipment); (d) parallel connection of loads



capacity will be six times the capacity of a single battery element).

When several loads (resistors) are inserted into an electric circuit in series (Fig. 175*c*), the current has only one path through which it can flow. Therefore, the total circuit resistance is equal to the sum of resistances of all individual loads, and the current is the same at any point of the circuit.

In a parallel circuit (Fig. 175*d*), the current has as many paths as there are loads (resistors) in parallel. These paths are sometimes called branch circuits. The total current flow in the circuit is equal to the sum of the currents flowing through all loads (branch circuits). Current flow through each branch will differ as the resistance of the load differs.

MAGNETISM. Each molecule in iron or in iron alloy has a north and a south pole. When not magnetized, the molecules are oriented randomly within the material. An iron bar can be magnetized through magnetic induction by striking a magnet over the bar to magnetize it, by placing the iron bar in a strong magnetic field, or by electromagnetic induction. These actions cause the molecules within the bar to align themselves with all north poles pointing in the same direction, forming what is known as magnetic lines of force. It is now an established fact that magnetic lines of force are essentially electrical in nature. They arise from the interaction between the spinning and orbiting electrons. When these electrons align so that their forces are combined, the iron bar is magnetized. A brief summary of basic facts about magnetism follows.

A magnet has a north and a south pole, and the magnetic lines of force leave the north pole and enter the south pole.

The concentration of magnetic lines of force is heaviest at the pole ends and decreases midway between the poles since magnetic lines have "like" polarity and therefore repel each other.

Like poles (charges) repel each other, and unlike poles (charges) attract each other.

Permanent magnets can be either natural or an alloy, such as nickel-iron, or aluminium-nickel-cobalt (magnetized), because these alloys have an atomic structure similar to iron. An alloy with a loose molecular structure allows magnetic lines of force to pass through itself more easily and is used as a temporary magnet.

BASIC FACTS ABOUT ELECTROMAGNETISM. A straight wire which carries current creates

a magnetic field around itself. The lines of force form concentric circles around the wire.

The magnetic field of a current-carrying conductor behaves in the same manner as the magnetic field of a permanent magnet, as long as current flows.

When the direction of current flow is changed, the direction of the lines of force also changes.

When two conductors carrying an equal current flowing in opposite directions are placed side by side, the lines of force are also in opposite directions and are more concentrated between the conductors than on the outside. The current-carrying conductors move apart to relieve the imbalance in the magnetic field.

If there is an equal current flow in the same direction through two or more parallel conductors, each conductor alone creates a circular magnetic field, and the lines of force move around all conductors in the same direction. The lines of force between the conductors move in opposite directions. Because the strength of each field is the same, the total magnetic effect between the conductors is canceled. The conductors will tend to move toward each other causing the magnetic effect to increase as the lines of force from each conductor join and surround the conductors.

When a straight current-carrying conductor is formed into a single loop, an electromagnet is produced. All lines of force enter the inside of the loop on one side and leave on the other side.

When the number of loops (coil) is increased, the magnetic field increases.

Air is a very poor conductor of magnetic lines of force. The smaller the air gap, the greater the number of magnetic lines of force.

When a soft iron core is inserted into the coil, it forms a true electromagnet. The magnetic flux (lines of force) will increase as much as several hundred times, because the permeability of rough iron may be 2500 times that of air.

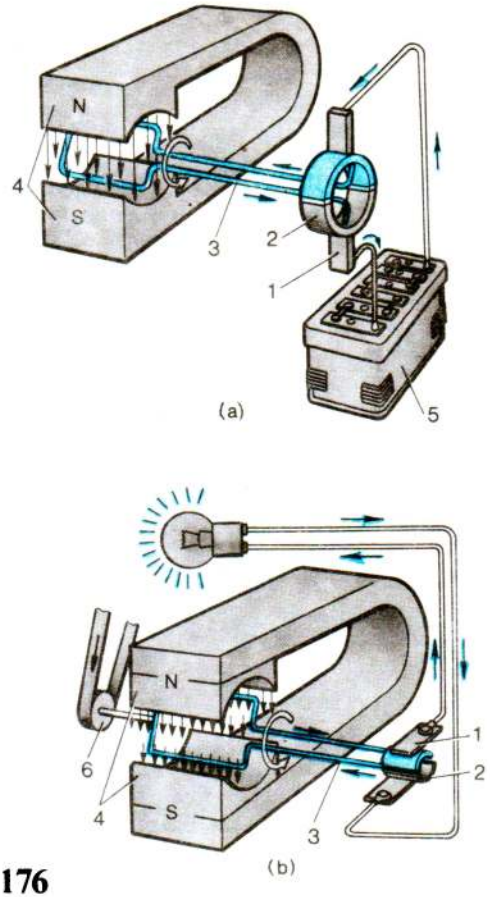
When the current flow through the coil is increased, the magnetic lines of force also increase proportionately.

The same magnetic force will be produced by an electromagnet having 1000 turns of wire carrying 10 A as that of an electromagnet having 200 turns of wire carrying 50 A. The number of turns times the amperes equals 10 000 ampere-turns in either case.

If a current carrying conductor is placed in the magnetic field of a permanent magnet (or electromagnet), the magnetic fields of the conductor and the magnet interact with the result that the conductor will tend to move across the field of the magnet, the direction of this movement depending on the direction of the current flow in the conductor. In this case, electrical energy is converted to mechanical energy. It is exactly this phenomenon that the operation of electric motors depends on.

Referring to Fig. 176*a*, the conductor here is formed into a loop and placed between the poles of a permanent magnet. The ends of the loop are connected to the terminals of a battery, so that current flows through the loop. When current flows in the loop, the conductor in the upper part of the loop tends to move to the left, while that in the lower part of the loop tends to move to the right. This causes the loop to turn counterclockwise. However, the rotation will stop when the loop reaches the center position between the poles of the magnet. To extend and equalize the force on the loop, the pole shoes are curved. To make continuous rotation possible, the loop ends are connected to a pair of sliding contacts (the commutator segments). A set of brushes is placed in a fixed position on the commutator to connect the battery with the loop. When the circuit is closed, the loop turns counterclockwise and coasts through the static neutral position. At the same time, the brushes slide onto the other commutator segments, thereby changing the direction of current flow in the loop, resulting in continuous rotation. In order to make the motor operate smoothly and more powerfully, many loops of wire are placed into slots in a cylindrical iron core (armature), and the ends of the loops are connected to a segmented commutator.

ELECTROMAGNETIC INDUCTION. If a conductor is moved between the poles of a magnet (or electromagnet) so that it cuts the magnetic lines of force, or if a magnet is moved over the conductor so that the magnetic lines of



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Illustrating the operation of simple electrical machines

(a) electric motor;
(b) generator;
1 – brush;
2 – commutator segment;
3 – conductor;
4 – magnet poles;
5 – battery;
6 – drive pulley

force cut the conductor, a voltage (emf) is induced in the conductor. The electromotive force (emf) obtained in this way is said to be an induced emf and the process is called electromagnetic induction. The polarity of the induced emf depends on the direction in which the conductor moves to cut the magnetic lines of force. When the conductor is moved parallel to the magnetic lines of force, no voltage is induced. The polarity of the induced voltage also changes when the polarity of the magnetic field is changed, provided the conductor maintains its direction of movement. Now, if the conductor is made to form part of a complete circuit, the induced emf will cause current to flow through the circuit. The phenomenon of electromagnetic induction is used to convert mechanical energy to electrical energy by means of electrical machines called generators.

Figure 176*b* illustrates the principle of operation of a simple direct-current (d.c.) generator. The generator consists of a loop (coil) of wire which is rotated between the poles of a magnet. As the loop rotates, voltage is induced in it. This voltage is carried to the segments of a commutator similar to the one used in the electric motor described earlier. In order for current to flow, a circuit must be set up, and this consists of brushes which rub against the commutator and pass the electricity to the wires of an external circuit including a load (a light bulb in our case). As the top and bottom conductors of the rotating loop pass the center point between the poles of the magnet, the direction of their movement relative to the magnetic lines of force is reversed, and so is the polarity of the induced emf in the loop. At the same time, the brushes slide onto the other commutator segments, with the result that the direction of current flow in the external circuit remains unchanged. If there were continuous sliding-contact rings instead of the segmented commutator, the flow of current in the external circuit would have reversed direction every time the conductors forming the loop pass the center point between the magnet poles, thus giving rise to alternating current. This is exactly how the alternating current (a.c.) generator, called the alternator, operates.

An alternator having only one rotating loop (coil) produces what is known as a single-phase current. There are also alternators which have three rotating loops (coils) arranged at an angle of 120° to each other. Such alternators generate a three-phase current.

TRANSFORMER. The transformer is a device that serves to change an alternating current of

one voltage to another voltage. In its simplest form, a transformer consists of two coils, one called the primary winding and the other, the secondary winding. The coils usually are wound on a laminated core of magnetic material, and the transformer is then known as an iron-core transformer. Sometimes, as in many radio-frequency transformers, there is no magnetic core. The transformer then may be described as an air-core transformer. In other types, as in the ignition coil, the core may consist of a bundle of fine iron wire or laminations, but the return flux is in air. This is called open-core construction. When an alternating current is passed through the primary winding, it induces a current in the secondary winding by producing an alternating magnetic field in the iron core. If the secondary winding has more turns than the primary winding, the voltage is increased and the current proportionately decreased. Such a transformer is known as a step-up transformer. If the secondary winding has less turns than the primary winding, the voltage is decreased but the current is increased in the same proportion. The transformer is in this case called a step-down transformer. In either case, the ratio of the voltage in the primary winding to that in the secondary winding is very nearly equal to the ratio of the number of turns in the primary winding to that in the secondary winding.

SEMICONDUCTOR DEVICES. As outlined earlier, a conductor must have less than four electrons in its valence shell, whereas an insulator must have more than four electrons in the valence shell. An element whose atom has four electrons in its valence shell is neither good conductor nor a good insulator. Four such elements are known. However, only two of these, namely, germanium and silicon, are used to make semiconductor devices, such as semiconductor diodes and transistors. Nowadays, silicon is more popular because it can withstand higher temperatures. The resistivity of germanium and silicon is extremely sensitive to minute additions of foreign substances (impurities) to the basic host crystal and may differ by orders of magnitude in different samples. When purified and prepared for doping (adding impurities), the germanium or silicon crystal is covalent bonded, i.e., all electrons in the crystal take part in forming covalent bonds between adjacent atoms, which increases the number of electrons in the valence shell. Each atom then has eight electrons in its valence shell and becomes a good insulator.

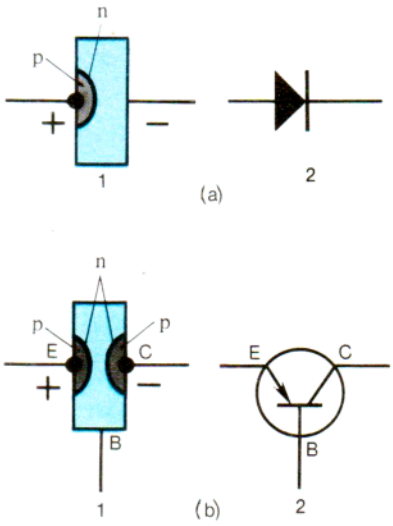
By doping the germanium or silicon material with a controlled portion of such elements as phosphorus or antimony (both of which have five electrons in their valence shells), covalent bonding will occur with one electron per each impurity atom left over. These free electrons become charge carriers and can be made to move easily through the material. The material of such structure is called *n*-type (for negative), that is, the material which has an excess of electrons.

When the germanium or silicon material is doped with such elements as aluminium or indium, which have three electrons in their valence shells, covalent bonds are incomplete, with the result that voids are created, one void per each impurity atom. These voids are called holes. The hole is actually a missing electron. Since the electron is the carrier of a negative charge, the hole may be assumed to be a positive charge carrier. By robbing an electron from the adjacent atom, the hole can be made to move as easily through the material as the free electron through the *n*-type material. The material of such structure is called *p*-type (for positive), that is, the material which has a deficiency of electrons.

In an electric field, electrons and holes will obviously move in opposite directions.

By adding different types and amounts of foreign atoms to different parts of the semiconductor crystal, it is possible to make certain regions *n*-type and others *p*-type. The transition region between *n*- and *p*-type material is known as a *p-n* junction. To have useful electrical characteristics, it is usually necessary that the transition from one type of conductivity to the other should be very rapid.

At a *p-n* junction an internal electric field is created, which is sufficient to prevent the drift of electrons from the *n*-side to the *p*-side of the



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Semiconductor devices

(a) diode;
(b) transistor;
1 – construction;
2 – symbol;
B – base;
C – collector;
E – emitter

junction, and the drift of holes in the opposite direction. If an external positive voltage is applied to the *p*-side and a negative voltage to the *n*-side, the internal field can be overcome and a substantial current will flow through the junction as a result of the tendency of the charge carriers on each side to migrate to the other side. The magnitude of the current will depend upon the applied voltage. In this case, the junction is said to be forward-biased. Reversing the voltage increases the effect of the internal field, and only a very small reverse current will flow through the junction. The junction is in this case said to be reverse-biased. The *p-n* junction is thus a very efficient rectifier, i.e., it conducts current in one direction only, and is widely used for this purpose. It is also the basis of the transistor.

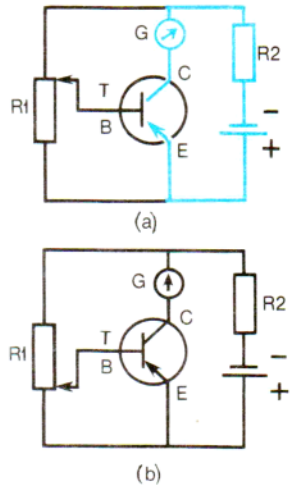
Devices using *p-n* junctions for rectification purposes are called semiconductor diodes (Fig. 177*a*).

Special diodes, called breakdown, or Zener, diodes are used to stabilize voltage in a circuit, i.e., to keep the circuit voltage within definite limits. These diodes act like an electric switch that reacts to a predetermined value of circuit voltage to switch a transistor on and off. The diodes can safely conduct current in reverse bias when the reverse-bias voltage reaches a certain value. When the reverse-bias voltage is below this value, the diodes will not conduct current.

A semiconductor device composed of two *p-n* semiconductor junctions is called a transistor (Fig. 177*b*). The transistor is somewhat of an electric switch and, at the same time, an amplifier.

A transistor consists of two semiconductor junctions arranged back to back, so that either a *p-n-p* or an *n-p-n* structure is formed. In a *p-n-p* transistor, the thin central *n*-region is called the base, one *p*-region is called the emitter, and the other *p*-region, the collector. In an *n-p-n* transistor, the *p*-region is the base.

The current flowing through the base circuit of a transistor is called the base current, that in the emitter circuit is called the emitter current, and the current in the collector circuit is called the collector current. The base current is also known as the signal, or input, current, for it is this current that controls the conductivity of the transistor. Almost all of the current flowing through the transistor is carried by the collector circuit into which the load supplied by the transistor is inserted. The collector current is therefore referred to as the load, or output, current. As mentioned above, the flow of current through the transistor is controlled by the base current. If there is no current in the base circuit, the resistance of the transistor is very high (several thousand ohms), and so there is no load current through the transistor. The transistor in this state is said to be cut off, or nonconductive. Making a small current flow through the emitter-base junction will cause the load current to flow through the transistor. The transistor in this state is said to be turned on, or conductive. The magnitude of the load current



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Illustrating the operation of a transistor

(a) transistor conductive; (b) transistor nonconductive; B – base; C – collector; E – emitter; G – galvanometer; R_1 – potentiometer; R_2 – load resistor

will depend on the extent of bias on the base. By suitable design the transistor can be made to give a load current some 20 to 100 times the base current, and so current amplification will take place.

Transistors are used both to amplify and interrupt the flow of current in various circuits.

Referring to Fig. 178, consider the operation of a *p-n-p* transistor in a simple switching circuit.

When the wiper of the potentiometer R_1 is in its uppermost position (Fig. 178*a*), the potential at the base is equal to that at the collector. In this case, the transistor is turned on and the maximum possible load current flows through it.

The load current flows from the positive terminal of the power supply source (battery), through the emitter-base (E-B) junction of the transistor, the base-collector (B-C) junction of the transistor, the galvanometer *G*, the load resistor R_2, and to the negative terminal of the power supply source, as shown in blue ink in Fig. 178*a*.

When the wiper of the potentiometer R_1 is in its lowermost position (Fig. 178*b*), the potential at the base of the transistor is equal to that of the emitter. In this case, no current can flow through the base circuit, and so there is no load current through the transistor. The transistor is thus cut off.

By moving the wiper of the potentiometer R_1 up or down from its central position, the load current can be increased or decreased accordingly.

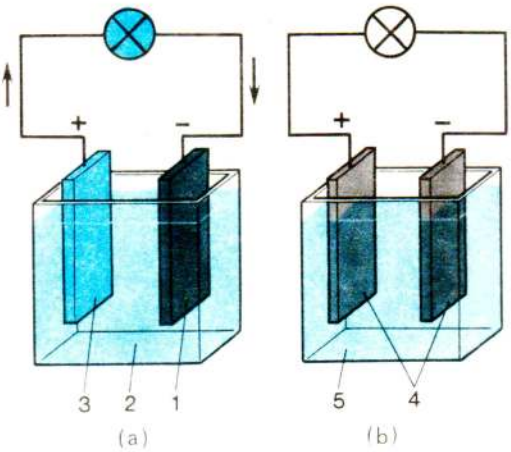
18.2. Storage Battery

The storage battery, or simply battery, serves to supply power to the using equipment of tractors and automobiles when the engine is stopped or is running at a slow speed. It consists of a number of identical cells containing individual battery elements that are connected in series.

The battery is an electrochemical device that converts electrical energy to chemical energy (during charging) and then converts chemical energy back to electrical energy (during discharging). The tractors and automobiles considered in this book use lead-acid storage batteries.

In its simplest form, a lead-acid battery (Fig. 179) comprises two lead plates placed in a plastic container filled with an electrolyte (a solution of sulfuric acid and distilled water). The plate surfaces immersed in the electrolyte become coated with a thin layer of lead sulfate.

To make the battery operative, it must be charged, i. e., an electric current must be passed through it. When a d. c. current, supplied by an external power source, flows through the battery, a chemical action takes place inside of it, as a result of which lead sulphate on the plate connected to the positive terminal of the power source gradually changes to lead peroxide *3*, while lead sulphate on the plate connected to the negative terminal of the power source



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Illustrating the operation of a simple lead-acid battery

(a) beginning of discharge;
(b) end of discharge;
1 – sponge lead;
2 – sulfuric acid solution;
3 – lead peroxide;
4 – lead sulfate;
5 – weak sulfuric acid solution

changes to sponge lead as gradually, sulfuric acid leaving the plates and returning to the electrolyte, thus increasing its density. Now, if a light bulb is connected to the plates, it will come on. Consequently, chemical energy that has been stored in the battery during charging converts to electrical energy during discharging.

A BATTERY (Fig. 180) consists of case *4* partitioned into cells. Each cell contains one battery element. The battery case is made from an acid-resistant plastic compound or hard rubber. On the bottom of the cells, there are ribs that serve to support the battery plates and form sediment chambers which allow the active material that wears off during charging and discharging to settle without interfering with the plates. Such interference would cause a short circuit. Each battery element comprises positive plates *2* and negative plates *1* assembled into two separate groups, the plates in each group being welded to a plate strap. The plates are made from a lead-antimony alloy in the form of a grid into which an active material – a lead oxide paste – is pressed. The positive plates are placed between the negative ones, and therefore the negative plate group has one more plate to cover the positive plate. This improves the chemical action during charging and discharging. Each plate is separated from its neighbouring plates by means of porous separators *9*. The separators may be fabricated from specially treated wood, microporous plastic, or fiberglass mat. They prevent contact between the plates, provide space for the electrolyte to contact the plates, and allow for free passage for the escaping gas. Each cell is covered by individual cover *6* which is provided by filler plug *5*. The plug serves two purposes. It can be removed so that the condition of the electrolyte can be checked and water added when necessary. It also has a hole through which the gas, formed during charging, can escape. The plate strap terminals are brought through the cell covers, so that connectors can be welded to them when the cells are joined together. In the assembled battery, the edges of the cell covers are sealed with a special acid-resistant mastic.

The quantity of electricity that a fully charged battery can deliver while being discharged at a constant rate (current) until its terminal voltage falls to a definite value is called the *capacity of the battery*. It is measured in ampere-hours (A h). The ampere-hour capacity of a battery depends on the number and size of the plates; it is roughly proportional to the plate area. Batteries, therefore, are built with many thin plates, so that the electrolyte may come into contact with as much active material as possible.

The electrolyte is prepared from chemically pure sulfuric acid and distilled water. The acid and water are mixed in an acid-resistant container by pouring the acid very slowly into the water. (Pouring water into the concentrated acid will cause a violent reaction like an explosion, with the result that the acid will be thrown out of the container and cause blisters if it contacts the skin directly; it will also damage clothes and deteriorate iron, paint, etc.).

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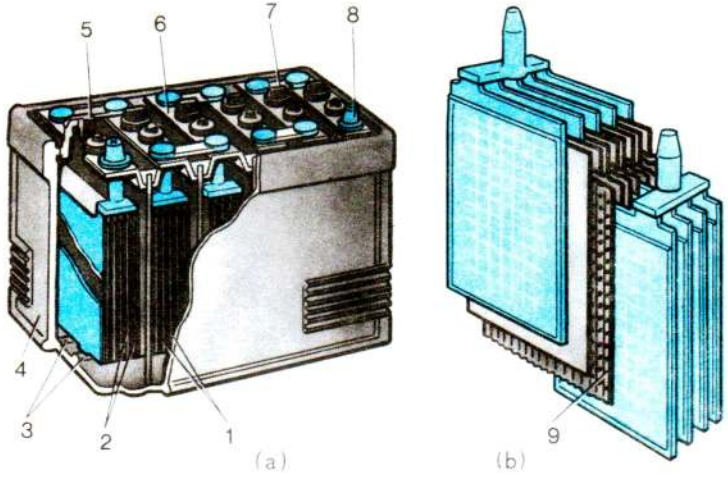
Storage battery

(a) external view;
(b) battery element;
1 – negative plate;
2 – positive plate;
3 – ribs;
4 – battery case;
5 – filler plug;
6 – cell cover;
7 – cell connector;
8 – terminal (battery) post;
9 – separators



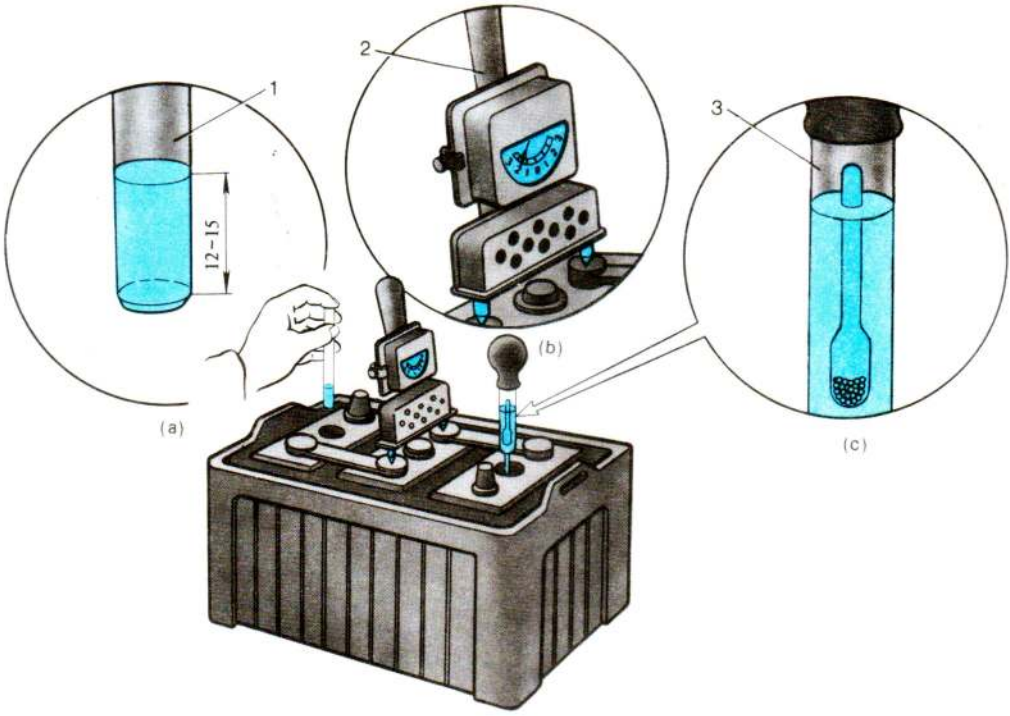
The electrolyte is a solution of about 65% water and 35% sulfuric acid by weight or about 76% water and 24% sulfuric acid by volume. The exact proportions of the acid and water in the electrolyte are determined by the density of the electrolyte.

The electrolyte density must suit the climatic conditions of the region where the electrolyte is to be used (see Table 2). In central regions with winter temperatures not below – 30°C, the electrolyte density in a fully charged battery must be kept at 1.27 all the year round. In regions with lower winter temperatures the electrolyte density must be higher, and in regions with higher temperatures, lower.

The electrolyte density is checked with a hydrometer (Fig. 181). As the battery discharges, the electrolyte density decreases. The level and density of the electrolyte should be checked in each battery cell. The electrolyte level should be 12 to 14 mm above the top edge of the plates. Should it prove to be too low, distilled water should be added, because the acid does not evaporate. Should the electrolyte be lost through accidental spilling, fresh electrolyte solution should be added.

Table 2

Climatic region	Season	Electrolyte density at 15°C			
		as poured in battery	at end of first charging	25% discharge	50% discharge
Winter temperatures below – 40°C	Winter Summer	1.29 1.25	1.31 1.27	1.27 1.23	1.23 1.19
Winter temperatures not below – 40°C	All the year round	1.27	1.29	1.25	1.21
Winter temperatures not below – 30°C	All the year round	1.25	1.27	1.23	1.19
Southern regions	All the year round	1.23	1.25	1.21	1.17



181

Checking storage battery

(a) checking electrolyte level;
(b) checking cell voltage;
(c) checking electrolyte density;
1 – glass tube;
2 – high-rate discharge tester;
3 – hydrometer

The electrolyte density is a fairly good indicator of the battery state of charge. But to determine the state of charge more accurately, use should be made of a high-rate discharge tester (Fig. 181*b*). The instrument comprises a voltmeter equipped with prods and a shunt resistor between the prods. Test each cell in turn. To do this, press the prods of the tester tightly against the cell terminals for five seconds and read the voltmeter. The cell voltage in a fully charged battery should not fall below 1.7 V.

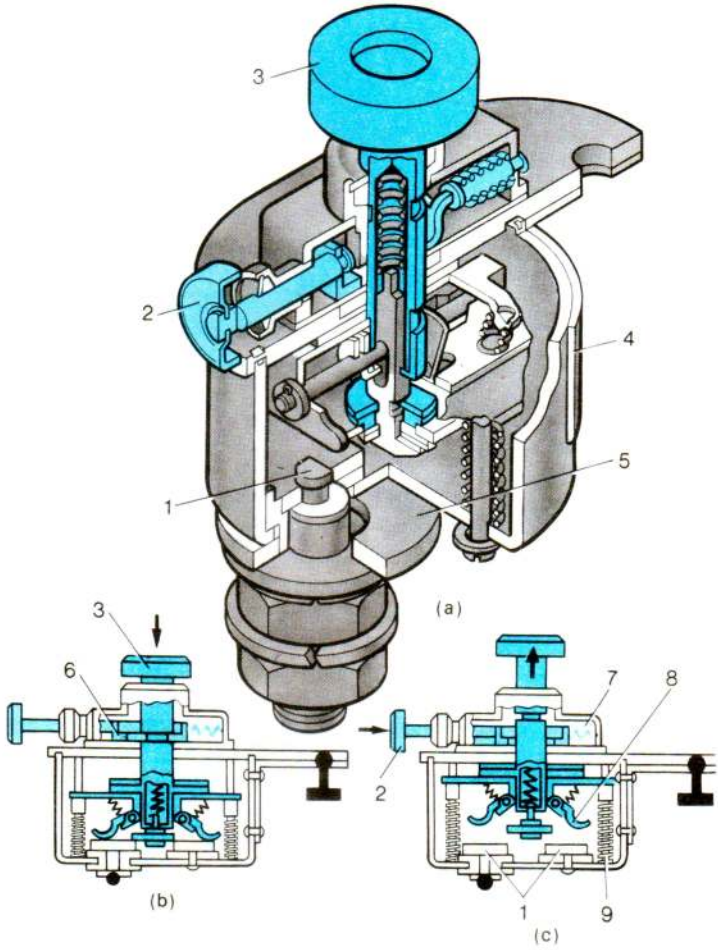
The difference in voltage between the individual cells of a battery should not exceed 0.1 V. If this difference should prove to be greater, or if the battery is discharged more than 50% in winter or more than 25% in summer, the battery should be removed from the vehicle and sent to a charging station for charging. Never allow your battery to stay half-charged for a long time, for this may cause damage to the battery. To avoid damaging the battery plates, never operate the starter motor for more than 30 seconds at a time. Never operate the motor repeatedly without pausing a few minutes before making another try.

When the battery is installed on a vehicle, the negative terminal is connected to the "ground", i. e., the chassis frame, via a battery ground switch, also known as the master switch. The purpose of *the battery ground switch* (Fig. 182) is to disconnect the battery from the electrical system when the engine is stopped for any lengthy period of time, or when the vehicle is parked, in order to reduce the self-discharge of the battery, avoid accidental short-circuiting

182

Battery ground (master) switch

(a) construction;
(b) and (c) illustrating the operation of the switch;
1 – fixed contacts;
2 – smaller button;
3 – larger button;
4 – body;
5 – insulating washer;
6 – locking plate;
7 – locking spring;
8 – movable contact;
9 – return spring



and diminish fire hazard. The battery ground switch is installed in the driver's cab and is placed in the "ON" position by depressing larger button *3*. As the button is depressed, movable contacts *8* are tightly pressed against stationary contacts and are held in this position by locking plate *6* loaded by spring *7*. The plunger of the larger button is provided with an annular groove, and as the plunger moves past the locking plate, the spring forces the plate to enter the groove and thus lock the plunger in position.

To disconnect the battery from the system, one has to depress smaller button *2*. This will cause the locking plate to move against spring pressure and leave the annular groove in the plunger of the larger button, thus releasing the plunger. Now, return springs *9* will move the plunger together with the movable contacts back to its initial *("OFF")* position.

BATTERY TROUBLES. The most common troubles are caused primarily by poor battery excessive self-discharge, called the leakage, premature discharging, internal short circuits, and sulfation of battery plates. All these troubles are caused primarily by poor battery servicing.

Battery leakage is considered excessive if the battery loses more than 1% of its capacity during 24 hours. Excessive battery leakage may

be caused by foreign matter getting into the electrolyte. It may be also due to current leaking over moist surface of the sealing mastic or the battery case. To avoid this trouble, the battery cell covers should be regularly cleaned and wiped dry with a clean rag. A better way to dry the battery is to use compressed air, but do not fail to tape or block the vent holes.

A premature discharging of one of the battery cells affects the operation of the entire battery. Such a battery cell is said to be "lagging". If the battery is drained beyond the point where the lagging cell is completely discharged, the cell will reverse its polarity, which will ruin the battery shortly.

An internal short circuit may be caused by a damaged separator. A battery which has even a single cell shorted out must be discarded.

Battery plates sulfate if the battery is kept discharged for too long a period of time, or if the electrolyte level is too low. Plate sulfation is the formation of a layer of lead sulfate crystals on the surface of the plates. This layer does not dissolve in the electrolyte and prevents it from contacting the active material, which lowers the battery voltage, increases the resistance of the plates, and reduces the capacity of the battery. The starter motor, if allowed to operate for too long a period of time, runs the battery down excessively and thus also adds to the sulfation of the battery plates. Badly sulfated plates cannot be restored.

Handle the battery with care. Do not spill the electrolyte during filling operations. It is an acid that can give you serious skin burns. If it gets in your eyes, it can cause blindness. If through necessity you are forced to mix your own electrolyte from a concentrated sulfuric acid, do so with extreme care. Wear rubber gloves, goggles, boots, and an apron. Never approach the battery area with an open flame. Do not smoke when checking or testing the battery. The gases formed during charging are highly explosive; therefore, the possibility of an explosion is always present.

If you get the electrolyte on your skin, flush it off at once with plenty of water. Then sprinkle baking soda on the contacted area, or wash the area with a 10% ammonia solution.

18.3. Generators

Nowadays, tractors and automobiles are equipped with three-phase a.c. generators known as alternators. The magnetic field in an alternator is produced by a field winding (coil) which is fed with direct current. When starting the engine, the field current is supplied by the battery. When the engine is running fast enough, the alternator takes over the job as the source of electric current, the a.c. output of the alternator being changed to direct current by a rectifier.

Automotive alternators may have either a stationary or a rotating field winding.

ALTERNATOR WITH A STATIONARY FIELD WINDING (Fig. 183). Such alternators have found extensive application on farm tractors and self-propelled grain combine harvesters. This is explained by the fact that these electrical machines are simple in design, reliable in operation, and easy to service.

The alternator is a three-phase, brushless, enclosed generator with a built-in rectifier assembly. It consists of stator *3*, two end shields *10* and *12*, and rectifier assembly *6*.

The stator is made up of electrical sheet steel laminations and has nine poles carrying stator coils *2*. Three coils in series constitute one phase winding. The finishes of the three phase windings are connected to the rectifier assembly, while the starts of the windings are connected together. The stator windings are thus star-connected. The stator is sandwiched between the end shields. Rear end shield *12* carries two terminal blocks. One of them has three terminals marked F *(field)*, R *(rectifier)*, and Gr *(ground)*. Two terminals *1* of the other block are marked a.c. (alternating current). The alternator mounting brackets are cast integral with the end shields.

The alternator rotor is made up of electrical sheet steel laminations shaped like a six-pointed star. The rotor packet (spider) is rigidly fixed on a shaft. The rotor shaft is supported by two roller bearings housed in the end shields. The bearings are sealed for life, and so they do not require lubrication. The field coil (winding) is held stationary on a steel core

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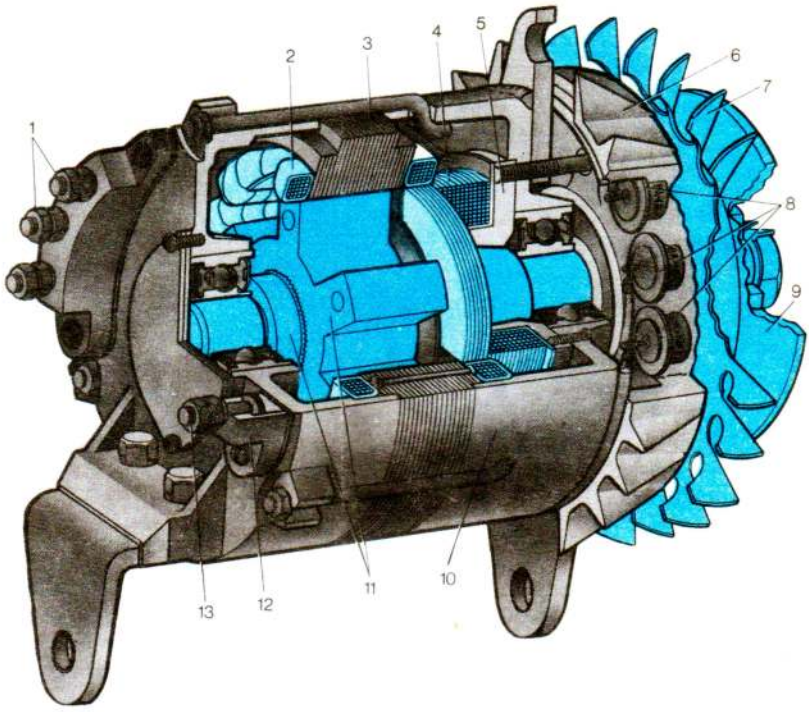
Alternator with a stationary field winding

1 – a.c. output terminals;
2 – stator phase winding;
3 – stator;
4 – field coil (winding);
5 – field coil core bushing;
6 – rectifier assembly;
7 – fan;
8 – rectifier diodes;
9 – alternator drive pulley;
10 and 12 – front and rear end shields;
11 – rotor shaft and spider;
13 – field terminal



bushing and is supplied with direct current via the Gr and F terminals.

When the rotor rotates, the arms of the rotor spider move close to the end face of the field coil core. The magnetic flux produced by the field coil links with the rotor spider through the air gap between the end face of field coil core bushing *5*. The magnetic flux (lines of force) of the rotor cuts the turns of stator coils *2* and induces an a.c. current in them, which is then rectified by the rectifier assembly.

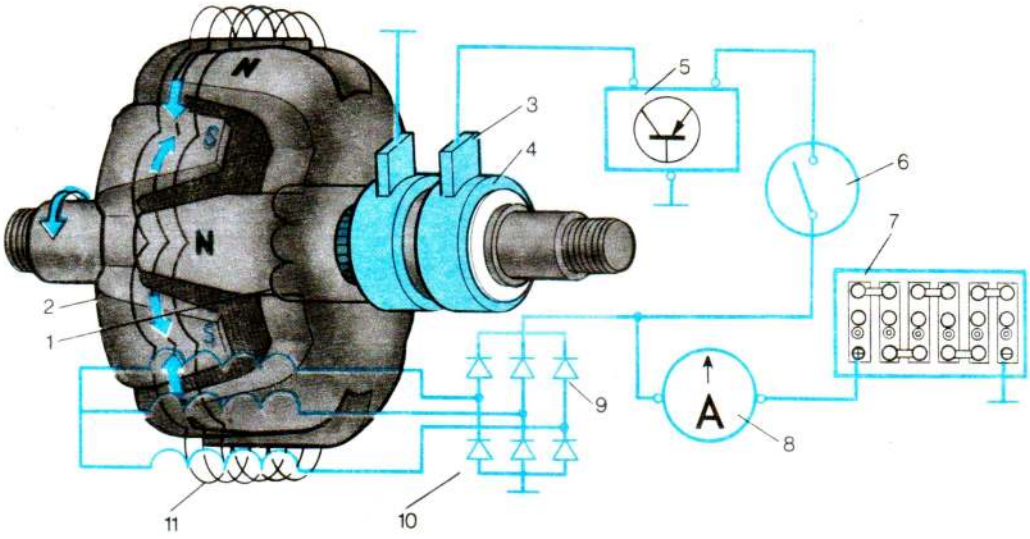
Rectifier assembly *6* comprises six rectifier diodes *8* which are pressed in a special plate called the heat sink. The diode terminals are grouped in pairs and connected to the phase windings of the alternator. The body of the rectifier assembly is finned and screwed to the front (drive) end shield of the alternator.

The alternator is belt-driven from the engine by means of pulley *9* keyed to the alternator rotor shaft and fixed in place with a nut. Fixed to the drive pulley on the alternator side is fan *7* that serves to cool both the rectifier assembly and the alternator.

ALTERNATOR WITH ROTATING FIELD WINDING (Fig. 184). Such alternators are used on automobiles. The alternator consists of a stator, a rotor, and a rectifier assembly.

The ring-shaped stator is made up of electrical sheet steel laminations and has eighteen poles on its inside surface, each pole carrying coil (winding) *11* of five turns. Thus, each phase winding here consists of six coils connected in series. The phase windings are star-connected and their output leads are connected to the diodes in the rectifier assembly.

Magnetic field in the alternator is produced by field coil *1* equipped with two interlacing finger-type pole pieces *2* that form twelve poles of alternating polarity. The field coil is wound onto a laminated core bushing fitted on the rotor shaft, and the pole pieces are spaced evenly over the field coil and are keyed to the shaft. The coil ends are connected electrically to two slip rings *4*. The field coil is fed with direct current furnished by storage battery *7*, via



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Illustrating the operation of an alternator with a rotating field winding

1 – field winding (coil);
2 – rotor pole piece;
3 – brush;
4 – slip ring;
5 – alternator regulator;
6 – ignition switch;
7 – storage battery;
8 – ammeter;
9 and 10 – rectifier diodes;
11 – stator winding

ignition switch *6*, regulator *5*, and brushes *3* which make a sliding contact with the slip rings.

As the alternator rotor revolves, the magnetic lines of force of the rotor field cut the turns of stator coils *11*, thus inducing an alternating current in them. This current is fed to silicon rectifier diodes in the rectifier assembly. The diodes rectify the a.c. output of the alternator and supply direct current to the external circuit. The operation of the alternator is monitored by reading ammeter *8* mounted on the instrument panel in the driver's cab.

The speed of the engine, hence of the alternator driven from its crankshaft, varies within fairly broad limits. As a result, the voltage produced by the alternator does not remain constant, but varies in accordance with the engine speed. The higher the engine speed, the higher the alternator voltage and vice versa. The using equipment in the automobile electrical system cannot tolerate these variations in the supply voltage. The alternator voltage, therefore, must be controlled.

To maintain the alternator voltage at a constant level irrespective of the engine speed and to protect the alternator against overload, use is made of alternator regulator *5*.

TRANSISTORIZED (TRANSISTOR-ASSISTED) ALTERNATOR REGULATOR (Fig. 185). The alternators described above use transistorized regulators. Such a regulator consists of a transistor-assisted voltage regulator, protective relay *5*, and seasonal control switch *11*. All the three devices are mounted on base *1*. The base carries two insulated terminals marked R (rectifier) and F (field) and one noninsulated terminal marked Gr (ground).

The transistor-assisted voltage regulator comprises vibrating points voltage regulator VR, transistor *6*, resistors R_a, R_s, R_t, and R_B and semiconductor diodes D_1 and D_s.

The transistor is the switching element of the voltage regulator, which actually makes and breaks the field circuit of the alternator to control its field current and hence the output voltage. The transistor is controlled by the

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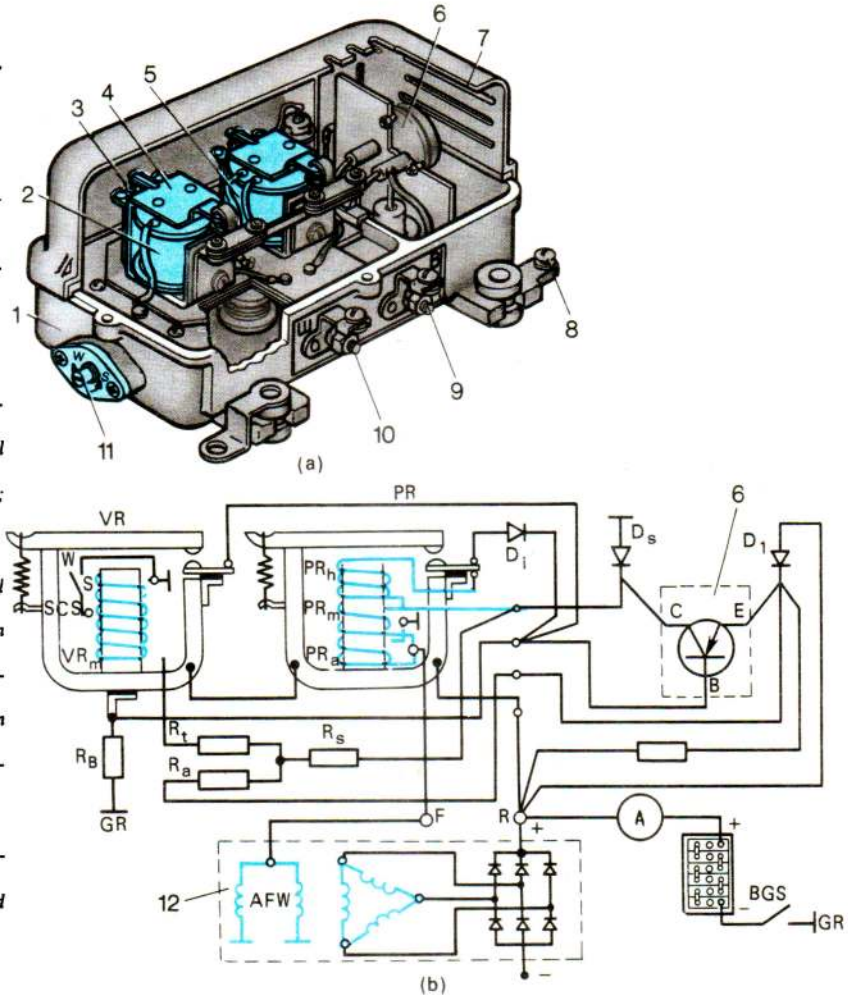
Transistorized alternator regulator

(a) construction;
(b) circuit diagram;
1 – base;
2 – voltage regulator winding;
3 – spring;
4 – voltage regulator armature and contact;
5 – protective relay;
6 – transistor;
7 – cover;
8 – ground terminal;
9 – alternator rectifier terminal (R);
10 – alternator field terminal (F);
11 – seasonal control switch;
12 – alternator;
VR – voltage regulator;
PR – protective relay;
SCS – seasonal control switch;
VR_m – voltage regulator main winding;
PR_h – protective relay holding winding;
PR_m – protective relay main winding;
PR_a – protective relay auxiliary winding;
D_i – isolation diode;
D_s – suppression diode;
AFW – alternator field winding;
BGS – battery ground switch;
B – transistor base;
C – transistor collector;
E – transistor emitter;
Gr – ground terminal;
R – alternator rectifier terminal (positive output);
F – alternator field terminal;
R_B – transistor base resistor;
R_t – temperature compensation resistor;
R_a – accelerating resistor;
R_s – field series resistor



vibrating points voltage regulator whose sensing element comprises winding *2* and spring *3*. The control element of the voltage regulator takes the form of normally open contacts (points) inserted between the positive terminal R of the voltage regulator and the base B of the transistor. The voltage regulator points carry only the small transistor control current (the base current) at a voltage of 1.5 to 2.5 V, which greatly extends the useful life of the vibrating points.

The alternator voltage is controlled as follows. When the engine speed is slow, so is the alternator speed, and the alternator output voltage is below its normal value corresponding to the calibrated setting of the voltage regulator. The pull produced by the voltage regulator main winding VR_m is insufficient to overcome the tension of spring *3* and attract regulator armature *4* to the core. In this case,

the regulator contacts stay open and the transistor is conductive, since current flows through the base circuit of the transistor, and it is this current that controls the conductivity of the transistor. The magnitude of this current is determined by the resistance of the resistor R_B inserted in the base circuit. The base current flows from the terminal R, through the diode D_1, the emitter-base junction of the transistor, and the resistor R_B to the ground.

With the transistor turned on, the field current of the alternator flows from the terminal R, through the diode D_1, the emitter-base and base-collector junctions of the transistor, the protective relay main winding PR_m, the terminal F, and the field winding AFW to the ground. The resistances in the field circuit are insignificant, and so the alternator is excited normally.

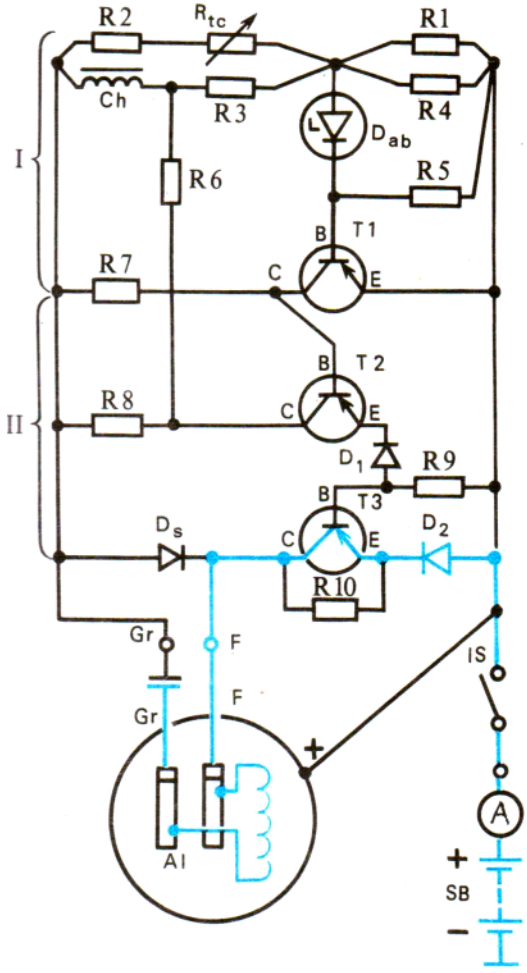
When the alternator voltage reaches the calibrated setting of the voltage regulator, the pull produced by the voltage regulator main winding becomes sufficient to overcome the tension of spring *3* and attract the regulator armature to the core and thus close the regulator contacts. As soon as the contacts close, the transistor is cut off because its base B becomes connected directly to the positive terminal R, so that the potential at the base becomes higher than the potential at the emitter E, the difference in potential being equal to the voltage drop across the diode D_1 which connects the emitter to the positive terminal R.

With the transistor cut off, the field current of the alternator drops suddenly, causing the field to collapse . The collapsing field causes an emf of self-induction to arise in the field winding. The current caused by the emf of self-induction is suppressed by the suppression diode D_s which thereby protects the control element of the voltage regulator against overvoltage. At the same time, the accelerating resistor R_a and series resistor R_s are inserted into the field circuit, and the alternator voltage is thus reduced. Spring *3* now overcomes the pull produced by the voltage regulator main winding and moves the regulator armature away from the core, thus opening the regulator contacts. The transistor is turned on again, and the cycle is repeated. This action keeps the alternator voltage within the preset limits (13.2 to 14 V with the seasonal control switch in the "S", i.e., summer, position).

To protect the transistor against ground faults in the alternator field circuit, use is made of protective relay *5* and the isolation diode D_i. The protective relay has three windings: the main (series) winding PR_m, the auxiliary winding PR_a, and the holding winding PR_h. The normally open contacts of the protective relay are connected via the isolation diode D_i in parallel with the voltage regulator contacts.

Should a ground fault occur in the alternator field circuit, the current in the main winding PR_m will increase, causing a corresponding increase in the magnetic field produced by the winding. As a result, the armature of the protective relay is attracted to the core and the relay contacts are closed. With the protective relay contacts closed, a positive potential is applied to the base of the transistor via the isolation diode D_i, the transistor is thus cut off. and the resistors R_a and R_s are inserted into the field circuit. This causes the current flowing through the grounded field winding to decrease. At the same time, the closed contacts of the protective relay provide supply for its holding winding PR_h whose magnetic field holds the relay armature attracted to the core. This prevents turning the transistor on until the battery ground switch BGS is opened and the ground fault in the field circuit cleared.

The seasonal control switch makes it possible to increase the alternator voltage in winter and decrease it in summer by 0.8 to 1.2 V. The seasonal control is effected by means of an additional coil wound over the main winding of the voltage regulator. The coil can be switched on and off to increase or decrease the total number of turns in the voltage regulator main winding and thus change the setting of the regulator. The switching is done by means of a contact screw carrying a contact disc on its end. To place the seasonal control switch in the "S" (summer) position, the contact screw is



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Schematic diagram of transistor alternator regulator of ЗИЛ-130 Model truck

A1 – *alternator;*
SB – *storage battery;*
T1 – *input (control) transistor;*
T2 – *amplifier transistor;*
T3 – *output (switching) transistor;*
D_{ab} – *avalanche breakdown (Zener) diode;*
D_s – *suppression diode;*
Ch – *choke;*
D_1 *and* D_2 – *diodes;*
R_{tc} – *temperature compensation resistor;*
R1 – R10 – *resistors;*
IS – *ignition switch;*
F – *field terminals;*
Gr – *ground terminals*

screwed out, and to place the switch into the "W" (winter) position, the screw is screwed in as far as it will go.

TRANSISTOR VOLTAGE REGULATOR. Some automobiles are equipped with a transistor voltage regulator (Fig. 186). The regulator has no contacts that could fail because of oxidation, and so it is more reliable than vibrating contact or transistorized regulators. The regulator consists of measuring circuit I and control circuit II.

The measuring circuit produces a signal required to cut off the transistors T2 and T3 in the control circuit as soon as the controlled voltage reaches the preset value (13.2 to 14.8 V). It consists of the silicon transistor T1, avalanche breakdown (Zener) diode D_{ab}, and a voltage divider built around the resistor R2, R_{tc}, R3, and choke Ch for one divider arm and the resistors R1 and R4 for the other arm.

The control circuit amplifies the signal produced by the measuring circuit and controls the field current of the alternator. The circuit includes two germanium transistors – the control transistor T2 and the output transistor T3, and also several diodes and resistors.

Both the regulator and the alternator field windings are supplied from the storage battery SB through one of the contacts of the ignition switch IS. When the rectified alternator output is lower than the controlled voltage, the diode D_{ab} permits no current to go to the base of the input transistor T1, and so it is cut off.

Since the base of the transistor T2 is connected through the resistor R7 to the negative terminal of the battery, while its emitter is connected through the diode D1 and the resistor R9 to the positive terminal of the battery, the transistor is conductive. With the transistor T2 turned on, the base of the transistor T3 is connected to the negative terminal of the battery, and its emitter is connected to the positive terminal of the battery via the diode D_2. The transistor T3 is thus also conductive.

The alternator field circuit (shown in blue ink) is as follows: the positive terminal of the storage battery SB – ammeter – ignition switch IS – diode D_2 – E-B junction of the transistor

T3 – B-C junction of the transistor T3 – field winding F of the alternator Al – ground Gr – negative terminal of the storage battery. With the transistor T3 turned on, the current flowing through the alternator field winding is sufficient for the alternator to produce a voltage of 13.2 to14.8 V at a moderate rotational speed of its rotor. If the alternator voltage is higher than the battery voltage, the regulator circuit and the field winding of the alternator are supplied by the alternator itself.

When the alternator voltage exceeds the controlled value, the Zener diode D_{ab} breaks down and conducts current to the base of the transistor T1, thus rendering it conductive. The transistor T1 now connects the base of the transistor T2 to the positive terminal of the storage battery. As a result, the transistors T2 and T3 are cut off, and the alternator field current now has to pass through the resistor R10, which reduces the field current and hence the alternator voltage. As the alternator voltage drops down, the Zener diode D_{ab} stops conducting current and cuts off the transistor T1.

As soon as the transistor T1 is cut off, the transistors T2 and T3 are turned on, and both the field current and output voltage of the alternator start increasing again. The transistors are turned on and off with a frequency of up to $300\ s^{-1}$, so that controlled voltage variations do not exceed 0.1 or 0.2 V.

The suppression diode D_s protects the output transistor T3 against breakdown. The temperature-compensation resistor R_{tc} is capable of reducing its resistance by a factor of 30 to 70 as its temperature grows from 0 to 100°C. In this way, the resistor automatically decreases the alternator voltage with rising temperature and increases it with decreasing temperature. The choke Ch serves to smooth out pulsations of the rectified alternator output and thus prevents the Zener diode from breaking down unintentionally.

ALTERNATOR TROUBLES. The most common alternator troubles are the following: a high charging rate with the battery charged and a low charging rate with the battery discharged. There could be other troubles, such as a noisy alternator or faulty ammeter. Noise is due to a loose mounting, a bad drive belt, or trouble inside the alternator. If the problem is inside the alternator, the alternator must be removed for bench checking. Bad bearings and some types of diode failure make noise.

If the alternator continues to push a high charging rate into a charged battery, the trouble is most likely in the regulator. The regulator should be removed and bench tested.

When the battery is low, the charging rate should be high. If the battery is run down and the alternator is producing little or no current, there is a trouble. It may be caused by a loose or defective alternator drive belt or by some defect in the alternator or regulator. First, it is necessary to make sure that the drive belt is in good condition and tightened to the proper tension. If it is, the wiring connections should be checked. A loose connection in the charging circuit can prevent current flow to the battery. The other possibility is some trouble in the alternator or regulator. This requires checking and the servicing of the alternator and regulator.

Review Questions

1. What is the purpose of the automotive electrical equipment?
2. List the automotive power supply sources and loads (using equipment).
3. List the materials used as conductors, insulators, and semiconductors.
4. What is the process that the generator and electric motor depend on for their operation?
5. What is the main property of the *p-n* junction?
6. What is the load current through the transistor?
7. How dense should the electrolyte be in batteries used in regions with winter temperatures not below – 30°C?
8. How can the state of charge of a battery be checked?
9. What are the causes of the sulfation of the battery plates?
10. List the possible storage battery troubles
11. What are the precautions to be taken when preparing the battery electrolyte?
12. What types of alternator do you know?
13. What is the purpose of the alternator regulator?
14. List the possible troubles of the alternator

Chapter 19
The Ignition System

19.1. Battery (Coil) Ignition

The compressed air-fuel mixture in the engine cylinders is ignited by sparks that jump the gap between the points of the spark plugs. The high-voltage surges necessary to produce the sparks at the spark plugs are provided by the ignition system components.

The battery, or coil, ignition system used in automotive engines serves to transform low-voltage current into high-voltage current and distribute it timely to the engine cylinders. The components of the battery ignition system are shown schematically in Fig. 187.

The battery ignition system includes two circuits – a low-voltage (primary) circuit and a high-voltage (secondary) circuit. The low-voltage circuit consists of battery *1*, ignition switch *3*, a series resistor, ignition coil primary winding *4*, and contact breaker *8*, all connected in series. The high-voltage circuit consists of ignition coil secondary winding *5*, distributor rotor *7*, high-voltage wiring, and spark plugs *10*, also connected in series.

When the ignition switch is closed, current flows through the primary winding of the ignition coil, provided that the contact-breaker points are closed, and produces a magnetic field around the winding.

When the engine runs, a cam, driven by the camshaft, opens the contact points at the exact instant a piston is close to the top of its compression stroke. Interrupting the flow of primary current causes the magnetic field to collapse. As the field collapses, its lines of force cut the turns of the ignition coil secondary winding, thereby inducing a voltage surge in the winding. The latter has many thousands of turns of very fine wire, and it is this high turn ratio that increases the voltage across the secondary winding terminals to a value of 20 to 24 thousand volts.

This high-voltage surge is delivered to the center terminal of the distributor cap where it is picked up by the rotor and directed to the proper spark plug. A spark jumps the spark plug gap and ignites the compressed air-fuel mixture.

THE IGNITION COIL (Fig. 188) consists of steel case *8*, core *4*, primary and secondary windings *6* and *5*, cap *2* of a plastic compound, and series resistor *3*.

The ignition coil is essentially a transformer whose steel core carries the secondary winding and the primary winding wound over it. The secondary winding is insulated from the core by an insulating tube, and the winding layers are insulated from each other by insulating paper. The primary winding is wound from insulated copper wire 0.8 mm in diameter. The secondary winding contains 18 to 20 thousand turns of wire 0.1 mm in diameter. One end of the secondary winding is connected to the primary winding, while the other is brought out to the high-voltage terminal in the center of the ignition coil cap. The ends of the primary winding are connected to terminals *1* on the cap.

Series resistor *3* is connected in series with the primary winding of the ignition coil. It is made of a spiral contained in a porcelain insulator. The resistor performs several important functions. During starting, the resistor is shorted out of the circuit to compensate for the lowered battery voltage caused by the heavy drain of the starter motor. At low engine speeds, the primary current flows through the resistor for a comparatively longer period of time, causing it to heat up, raising its resistance, and reducing current flow. This action keeps the ignition coil cooler and reduces the load on the distributor contacts. At high engine speeds, the current flows through the primary circuit for a comparatively shorter period, which causes the resistor to cool, allowing more current to flow. This increases the induced secondary voltage at high engine speeds, where it is needed because the efficiency of the ignition system falls off rapidly with speed.

Inside the ignition coil case, there is a yoke of electrical sheet steel. The coil core is made up of electrical sheet steel laminations and is

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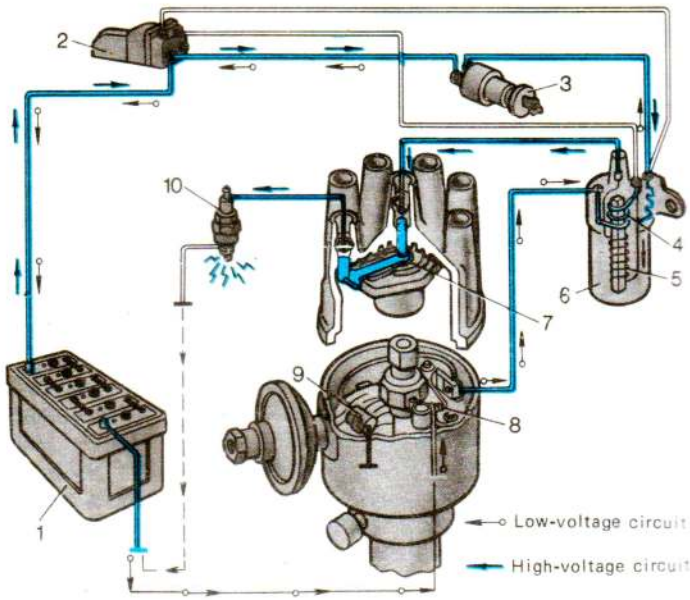
Schematic diagram of battery ignition system

1 – storage battery;
2 – starter motor switch;
3 – ignition switch;
4 – primary winding;
5 – secondary winding;
6 – ignition coil;
7 – distributor rotor;
8 – contact breaker;
9 – condenser;
10 – spark plug



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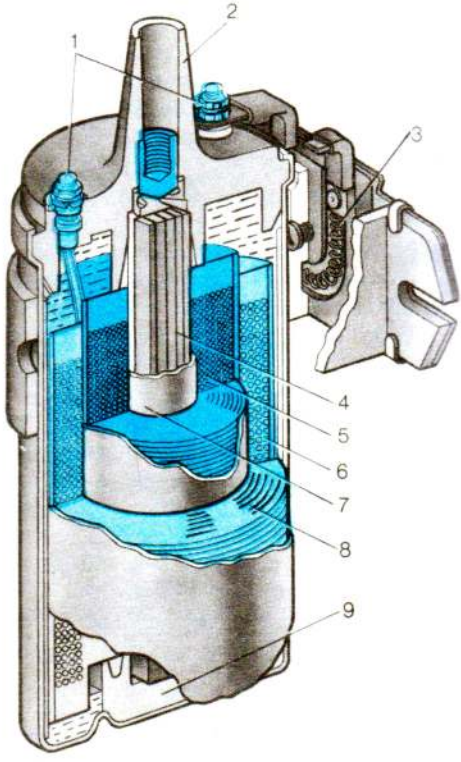
Ignition coil

1 – terminals;
2 – cap;
3 – series resistor;
4 – core;
5 – secondary winding;
6 – primary winding;
7 – insulating tube;
8 – case;
9 – porcelain insulator



supported by porcelain insulator *9* on the bottom of the coil case. The space between the coil windings and the case is filled with transformer oil.

THE IGNITION DISTRIBUTOR (Fig. 189) serves the purpose of interrupting the low-voltage primary current and distributing the resulting high-voltage surges to the engine cylinders in proper sequence and in "time" with the engine.

The distributor consists of body *10*, distributor drive shaft (spindle) *11*, a stationary and a movable disc making up what is known as the breaker plate assembly, distributor (breaker) cam *6*, and centrifugal and vacuum advance mechanisms. Movable breaker plate *15* carries insulated breaker (contact) arm *5*, which is pivoted on the breaker plate and carries moving contact point *7* on its end, and

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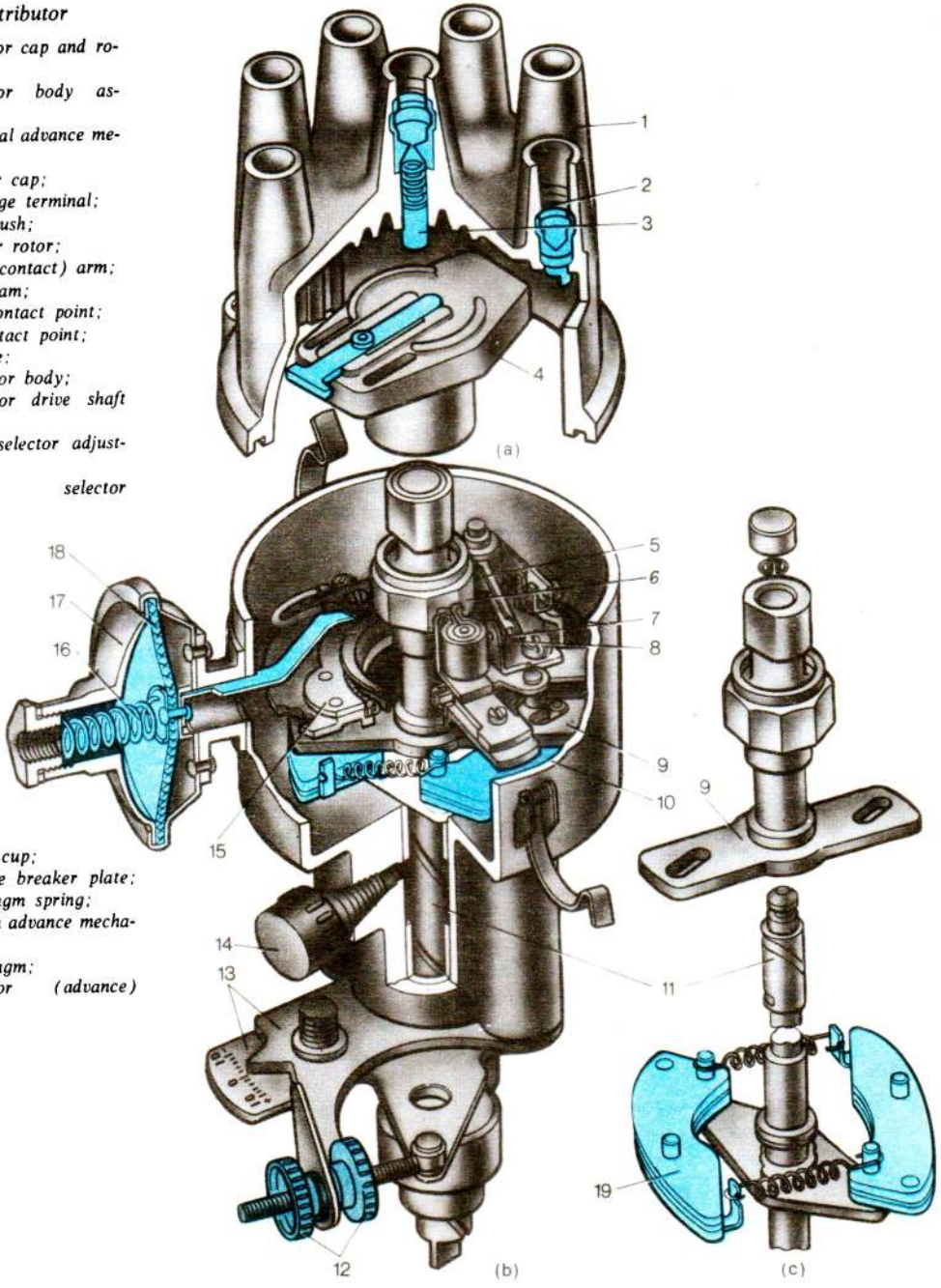
Ignition distributor

(a) distributor cap and rotor;
(b) distributor body assembly;
(c) centrifugal advance mechanism;
1 – distributor cap;
2 – high-voltage terminal;
3 – carbon brush;
4 – distributor rotor;
5 – breaker (contact) arm;
6 – breaker cam;
7 – moving contact point;
8 – fixed contact point;
9 – stop plate;
10 – distributor body;
11 – distributor drive shaft (spindle);
12 – octane selector adjusting nuts;
13 – octane selector assembly;
14 – grease cup;
15 – movable breaker plate;
16 – diaphragm spring;
17 – vacuum advance mechanism;
18 – diaphragm;
19 – governor (advance) weight



fixed contact point *8*, which is held to a support. The distributor contact points are made of tungsten to reduce the transfer of metal from one contact to the other. The moving contact point is pressed against the fixed one by the breaker arm leaf spring.

The lobes on rotating cam *6* act upon the insulated rubbing block of the breaker arm to open the contact points. There are as many lobes on the cam as there are cylinders in the engine, and the contact points open as many times during one revolution of the cam.

The breaker cam is connected to the distributor drive shaft through the intermediary of the centrifugal advance mechanism (Fig. 189*c*), and the distributor drive shaft is driven from the engine camshaft. When the engine is idling or running at low speed, the spark is timed to occur just before the piston reaches the top dead center on the compression stroke. At higher engine speeds, there is less time for the mixture to ignite, burn, and deliver its power to the piston. Consequently, at higher engine speeds, the spark must be delivered earlier in the cycle, and this is exactly what the centrifugal advance mechanism is designed to do. The centrifugal advance mechanism includes two governor (advance) weights *19* with short pins that fit in skewed slots in stop plate *9* held to the cam. As the engine speed increases, the governor weights throw out against spring pressure. This motion is transmitted to the cam through the stop plate, so that the cam is advanced relative to the distributor drive shaft. As a result, the distributor cam will open the breaker points earlier in the cycle, and the angle of ignition (spark) advance will thus be increased.

Under light engine load conditions, there is a high vacuum in the intake manifold caused by the restriction of the partially closed throttle valve. Consequently, there is a smaller amount of air-fuel mixture delivered to the combustion chambers. Because of the fewer fuel particles, the mixture will not burn as rapidly, therefore, ignition must take place earlier in the cycle.

To provide additional spark advance control, based on intake manifold pressure, a vacuum advance mechanism is incorporated in the distributor. Vacuum advance mechanism *17* consists of diaphragm *18* loaded by spring *16*, which rotates the movable breaker plate carrying the contact point set. The diaphragm space of the vacuum advance mechanism is connected on one side of the diaphragm to a vacuum passageway in the carburettor bore, which is located on the atmospheric side of the throttle valve when the engine is idling. The space on the other side of the diaphragm communicates with the atmosphere. When the engine is idling, no vacuum is applied to the diaphragm, and the breaker plate is held in position by spring pressure. As the throttle valve is opened, it swings past the vacuum port, thus applying vacuum to diaphragm. The diaphragm deflects to the left (in Fig. 189*b*) and rotates the breaker plate in a direction opposite to the rotation of the distributor cam, increasing the angle of ignition advance.

When the engine is accelerated, intake manifold vacuum drops according to the degree of throttle valve opening, and the diaphragm, forced by spring *16*, moves the breaker plate to decrease the angle of ignition advance accordingly.

OCTANE SELECTOR ASSEMBLY *13* serves to set ignition timing in accordance with the octane number of the fuel used. The device can change the angle of ignition advance within $\pm 12°$ of crankshaft rotation angle. To change ignition timing, the bolt fixing the plates of the octane selector assembly is loosened and the distributor body is rotated in the desired direction by turning adjusting nuts *12*. One scale division on the octane selector plate corresponds to a 2-degree change in ignition timing.

The distributor body is covered by cap *1* (Fig. 189 *a*) which houses distributor rotor *4*. The rotor is made of a plastic compound and has a contact blade embedded into its top surface. The rotor fits over the top part of the distributor cam sleeve. The distributor cap, also of a plastic compound, contains towers with terminals *2* for connecting the high-voltage wires leading to the spark plugs. The central tower receives the high-voltage output of the ignition coil that is passed onto the rotor for

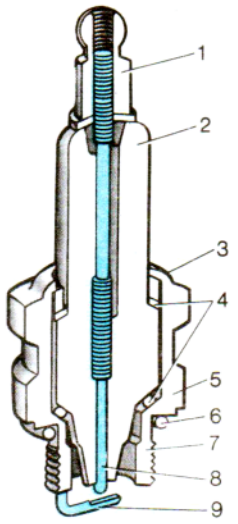
distribution to the spark plug wires. Inside the cover, there is a socket opposite the central terminal, which accommodates spring-loaded carbon brush *3* to connect the ignition coil high-voltage wire to the contact blade of the rotor.

When the distributor contact points open, the primary circuit is interrupted. But the flow of current cannot be stopped instantaneously. Because of inertia and self-induction, the current continues to flow and arc across the points. To stop this flow, a condenser is connected across the contact point, so that when the points start to open, the current surges into the condenser. By the time the condenser is fully charged, the contact points are open wide enough to prevent an arc. So, the current stops flowing, and the magnetic field collapses quickly. The speed of collapse is aided by the discharge of the condenser back through the primary winding of the ignition coil in a reverse direction.

The condenser, also called a capacitor, is made of two long strips of aluminium foil, with insulating strips of wax paper between them, rolled into a winding. The winding is placed into a cylindrical metal can. One of the two metal strips is connected by a central lead to the insulated (i.e., movable) contact point, while the other is connected to the can that is attached to the breaker plate.

THE SPARK PLUG (Fig. 190) serves to form a spark gap which is jumped by the high-voltage surge to ignite the compressed air-fuel mixture in the cylinder of the engine. The spark plug consists of metal shell *5*, insulator *2* with center electrode *8*, and ground, or side, electrode *9* welded to the shell. The lower part of the spark plug shell is threaded and its upper part has the shape of a hex nut. This allows one to use a wrench to screw the plug into its hole in the cylinder head.

The size of the gap between the spark plug electrodes is essential to the operation of the plug. Normal spark plug gap is in the range 0.7 to 0.9 mm. If it is necessary to adjust the gap, the adjustment should be made by bending the side electrode; bending the center electrode is sure to crack the insulator.



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Spark plug

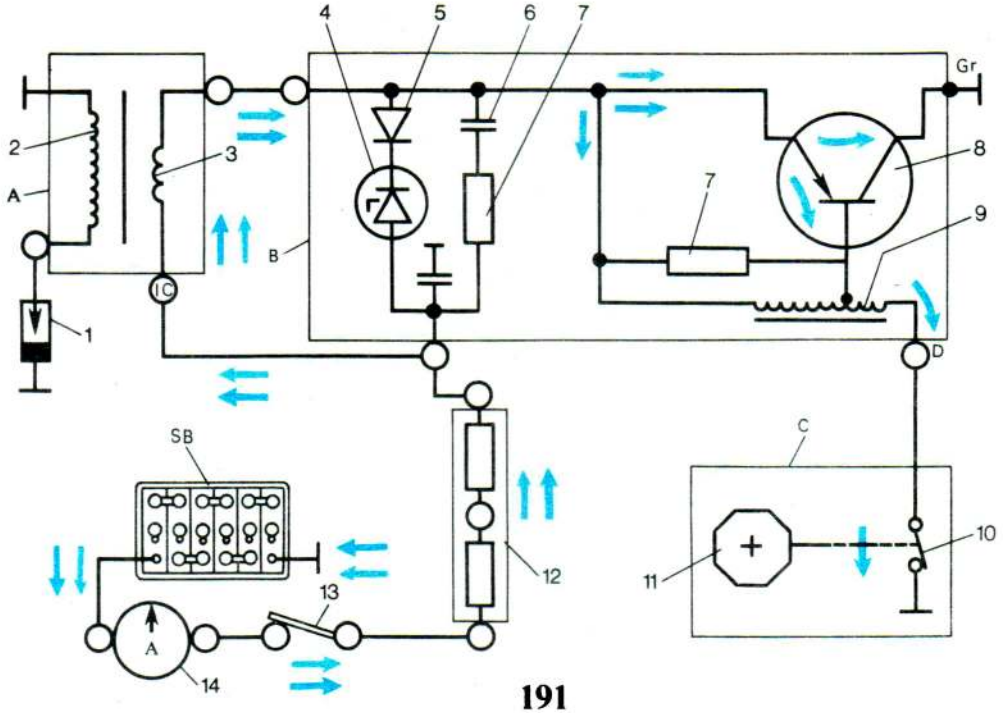
1 – terminal;
2 – insulator;
3 – roller-over shell edge;
4 – sealing gaskets;
5 – shell;
6 – spark plug gasket;
7 – threads;
8 – center electrode;
9 – ground (side) electrode

19.2. Transistorized (Transistor-Assisted) Ignition System

The battery ignition system is simple in design. That is why its use on automobiles is so extensive. However, the system suffers from substantial disadvantages: the breaker points wear rapidly as a result of burning since they break current of considerable magnitude; the magnitude of the high-voltage current depends on the engine speed; the system cannot provide for reliable ignition in high-speed engines with a large number of cylinders.

Modern automobiles use a transistorized ignition system which, although more complex, possesses a number of advantages over the battery ignition system.

The transistorized ignition system (Fig. 191) differs from the ordinary battery ignition system in that it has a solid-state commutator



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Transistorized ignition system

A – ignition coil;
B – commutator;
C – distributor;
SB – storage battery;
1 – spark plug;
2 – secondary winding;
3 – primary winding;
4 – Zener diode;
5 – isolation diode;
6 – capacitor;
7 – resistor;
8 – transistor;
9 – pulse transformer;
10 – breaker points;
11 – breaker cam;
12 – series resistor;
13 – ignition switch;
14 – ammeter;
IC, Gr, and D – terminals

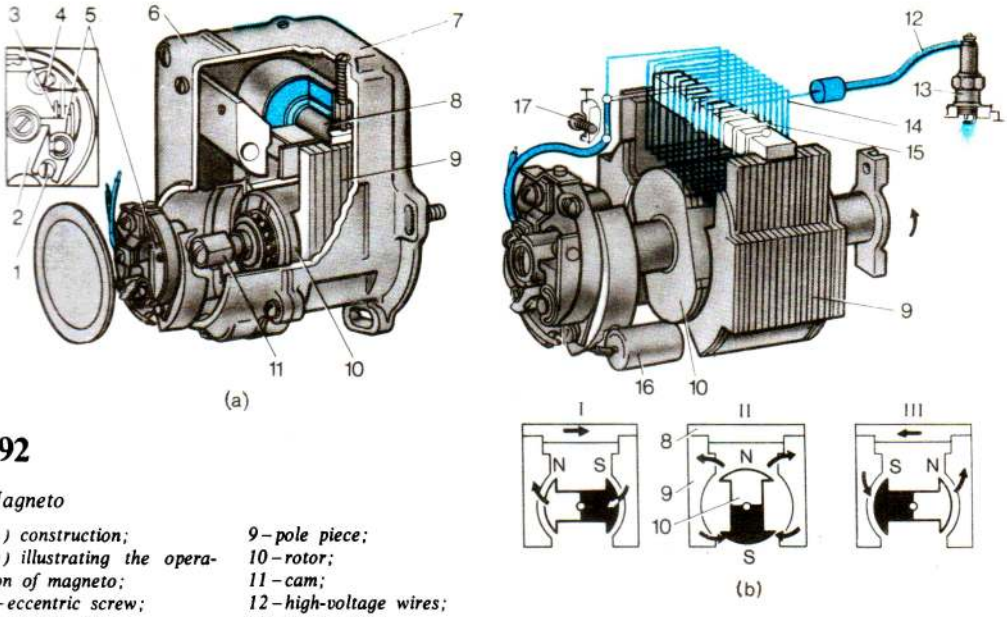
B connected between the breaker points of the distributor C and the ignition coil A.

The commutator is housed in a ribbed case cast in a zinc alloy. In the lower part of the case, there are protective circuit components of transistor *8*, pulse transformer *9*, and resistors. Located on a side wall of the case are four terminals, three of them marked Gr (ground), D (distributor), and IC (ignition coil) and one unmarked. The unmarked terminal serves to connect the commutator to a similar terminal of the ignition coil.

The commutator is essentially an electronic switch that can be either in the "on" state or in the "off" state. With the commutator in the "on" state (breaker points closed), there is a flow of current through the ignition coil primary winding. When the commutator is in the "off" state (breaker points open), no current flows through the primary winding of the coil. The blue arrows in Fig. 191 indicate the flow of current in the system when the commutator is in the "on" state.

Breaker points *10* are inserted into the base circuit of transistor *8*. When the points are closed, they carry a small current (0.75 A). Since the magnitude of the base current of the transistor is small, the breaker points suffer no electrical erosion and, therefore, wear only mechanically.

At the same time, the flow of current through the primary winding of the ignition coil, which is provided by the transistor, makes it possible



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Magneto

(a) construction;
(b) illustrating the operation of magneto;
1 – eccentric screw;
2 – contact plate;
3 – fixed point;
4 – contact point screw;
5 – moving point;
6 – cover;
7 – magneto casing;
8 – core;
9 – pole piece;
10 – rotor;
11 – cam;
12 – high-voltage wires;
13 – spark plug;
14 – secondary winding;
15 – primary winding;
16 – condenser;
17 – ignition switch (magneto grounding switch)

to attain a 25% increase in the secondary voltage as compared to that in the ordinary battery ignition system. This permits increasing the spark plug gap up to 1-1.2 mm. Wider spark plug gaps mean longer sparks, and long sparks ensure complete burning of the air-fuel mixture in the engine cylinders at any engine speed. Long sparks also ease starting the engine and improve fuel economy.

The transistorized ignition system uses an ignition coil with as many as 41 500 turns in the secondary winding and two-section series resistor *12*. There is no condenser across the breaker points.

Pulse transformer *9* serves to ensure a clear-cut and rapid switching of the transistor. The sharp fall of the primary current helps inducing a high voltage in ignition coil secondary winding *2*, but gives rise to a high emf of self-induction in the primary winding, which can harm the transistor. To protect the transistor against breakdown due to the self-induced voltage in the ignition coil primary winding, use is made of a protective circuit comprising Zener diode *4* and isolation diode *5*. If the self-induced voltage exceeds 100 V, the Zener diode breaks down and shunts the primary winding through the isolation diode.

19.3. Magneto Ignition System

This system is used on tractors equipped with internal combustion starting engines. The system is self-contained and has no connections with the tractor electrical system.

The system uses a special electrical machine called the magneto which generates electricity and transforms it to a high voltage when required. The magneto (Fig. 192) consists of casing *7* of a nonmagnetic zinc alloy, which houses steel core *8* fitted with laminated pole pieces *9*. Rotor *10* rotates between the pole pieces. The rotor is a two-pole permanent magnet fixed on a shaft that is supported by two ball bearings in the magneto casing. Keyed to the rear end of the rotor shaft is contact breaker cam *11*. The contact breaker comprises fixed point *3* and

moving point *5*. The fixed contact breaker point is mounted on a plate that is insulated from ground and connected to one end of the primary winding. The moving contact breaker point is grounded and is fixed to the contact breaker arm equipped with a textolite rubbing block. On the outside of the moving contact breaker point, there is a spring that pushes it against the fixed point. Connected across the contact breaker points is condenser *16*.

The magneto core carries two windings – primary winding *15* and secondary winding *14*, which form a step-up transformer.

The primary winding has a small number of turns of heavy wire. One end of the primary winding is soldered to the core and the other to the plate that carries the fixed contact breaker point and is grounded through the moving contact breaker point.

The secondary winding consists of a large number of turns of fine wire. One end of the secondary winding is connected to the primary winding. The other end of the winding is connected to the contact plate and, via high-voltage wire *12*, to the spark plug *13*.

The magneto operates as follows (Fig. 192*b*). When the rotor, i.e., the permanent magnet, rotates between the pole pieces, a magnetic flux is caused to flow through the pole pieces and also through the steel core that bridges them. When this happens, the lines of force in the magnetic field cut through the turns in the primary winding, causing a low-voltage (around 15 V) current to flow in the primary circuit. The circuit, of course, is complete when the contact breaker points are closed. This current produces a strong magnetic field around the primary winding. The cam opens the contact breaker points as it rotates. Opening the points breaks the primary circuit, which causes the magnetic field produced by the primary winding to collapse and, in the process, induce a high voltage (around 20 thousand volts) in the secondary winding. The condenser in this system, as in the battery ignition system, serves the purpose of absorbing the current which tends to jump across the contact breaker points. It also aids the speed of collapse of the magnetic field and thus intensifies the spark occurring at the spark plug. Switch *17* is used to stop the engine by grounding the primary winding.

Review Questions

1. What are the devices making up the battery ignition system?
2. What are the components of the low- and high-voltage circuits in the battery ignition system?
3. How is the ignition coil constructed?
4. What are the devices used to adjust ignition timing?
5. What is the purpose of the condenser?
6. What is the difference between the transistorized and ordinary battery ignition systems?
7. How is the magneto constructed?

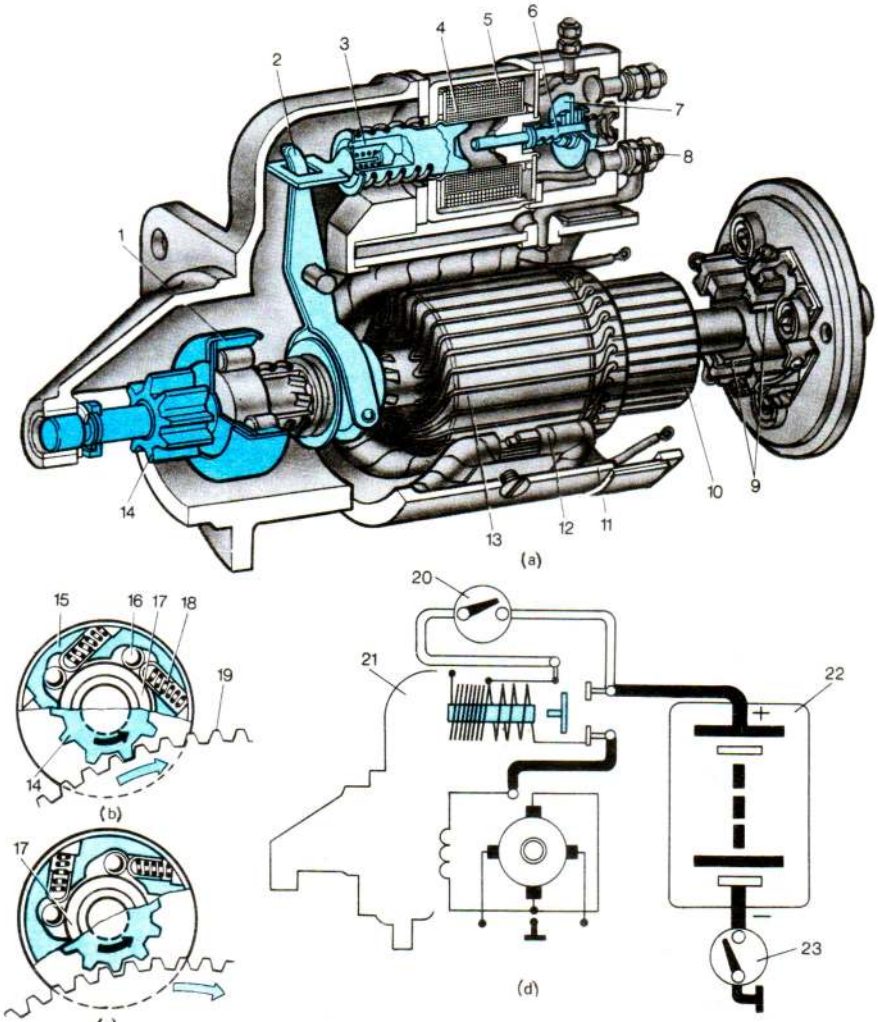
Chapter 20
Using Equipment (Loads)

20.1. Starter Motors

For a carburettor engine to start reliably, its crankshaft must be turned at a speed of 60 to 80 rpm. To manually crank the engine with such a speed requires much effort. That is why

Starter motor of i.c. starting engine

(a) construction;
(b) overrunning clutch in locked position;
(c) overrunning clutch in released position;
(d) illustrating the operation of the starter motor;
1 – overrunning clutch;
2 – shifting lever;
3 – solenoid switch plunger;
4 – pull-in winding;
5 – hold-in winding;
6 – contact disc stem;
7 – contact disc;
8 – terminal contact and bolt;
9 – grounded brushes;
10 – commutator;
11 – field frame;
12 – field-coil winding;
13 – armature;
14 – drive pinion;
15 – overrunning clutch casing;
16 – roller;
17 – overrunning clutch bushing;
18 – plunger;
19 – flywheel ring gear;
20 – starter switch;
21 – starter motor;
22 – storage battery;
23 – battery ground (master) switch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(d)

electric starting systems are now universally used. There are minor differences in design between starter motors used to start internal combustion starting engines of tractor diesels and those intended for direct starting of carburettor and diesel engines.

STARTER MOTOR OF I.C. STARTING ENGINE. The starter motor (Fig. 193) is a totally enclosed, series-wound d.c. motor. It converts electrical energy supplied by the battery into mechanical power for cranking the engine. The motor consists of field frame *11*, complete with pole shoes and field-coil windings *12*, armature *13*, brushes, a solenoid switch, and a drive pinion gear mechanism with pinion *14*.

The armature shaft is supported by plain bronze bushings. The slots in the armature accommodate a series of loops of heavy copper ribbon. The ends of each armature loop are soldered to individual segments of commutator *10* which is in sliding contact with four spring-loads brushes. Two brushes are grounded, and the other two are connected to one of the ends of the field winding. The other end of the field winding is connected to terminal *8* of the solenoid switch.

The solenoid switch includes a core carrying pull-in winding *4* and hold-in winding *5*, and plunger *3* attached to shift lever *2*.

The starter motor is energized by means of a key-operated starter switch *20* located on the instrument panel in the driver's cab. The starter switch terminals are connected one to the positive terminal post of the storage battery and the other, to one of the ends of the solenoid switch pull-in winding.

The solenoid switch windings are connected in series, but the hold-in winding is a shunt winding, its free end being connected to ground, whereas the pull-in winding is a series winding whose ends are connected across the starting switch contacts of the solenoid switch. When the starter switch is turned on, current is sent through both solenoid switch windings, causing a strong magnetic pull which is enough to draw the plunger into the switch body, shifting pinion *14* into mesh with the idler gear of the starting engine. When the plunger reaches the end of its stroke, it forces contact disc *7* against the starting switch (terminal) contacts, thus completing the starter motor circuit. This shorts out the pull-in winding. The hold-in winding is strong enough to keep the plunger in position until the solenoid switch is deenergized. The starter motor cranks the engine until it starts. Once the engine has started, it begins driving the starter motor at a very high speed because of the high gear ratio between the pinion and the flywheel ring gear. This causes overrunning clutch *1* to disconnect the pinion from the starter motor shaft. This clutch is similar to the one described in Section 9.3.

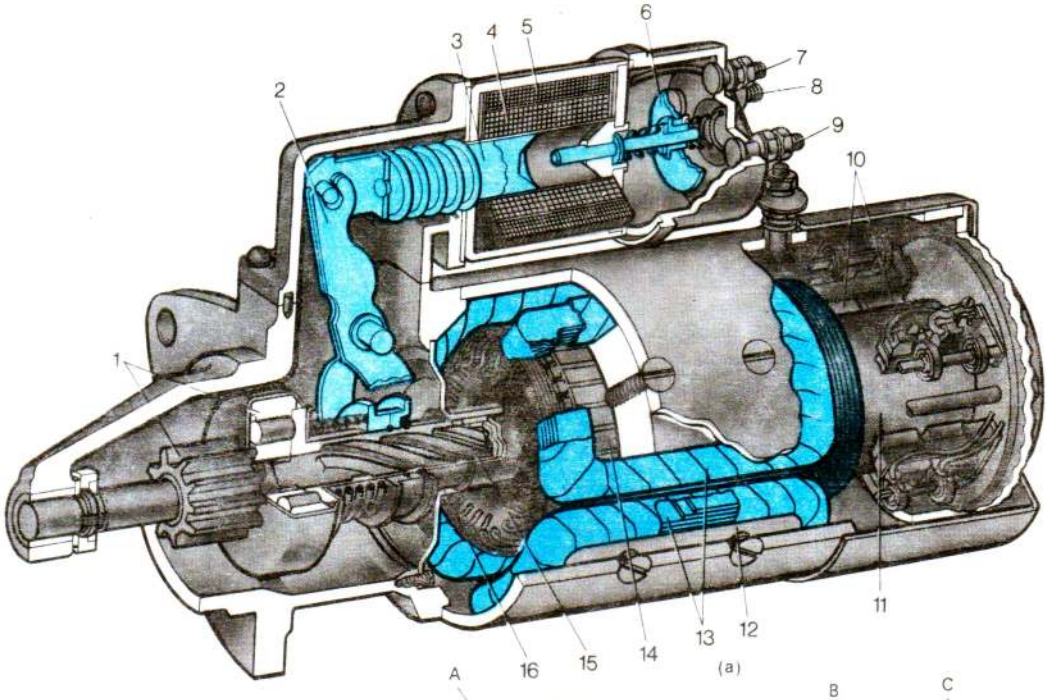
After the engine has started, the starter switch is turned off. This deenergizes the solenoid switch. The overrunning clutch assembly is shifted out of mesh with the idler gear, and the plunger releases the contact disc which breaks the starting switch contacts, thus deenergizing the starter motor.

STARTER MOTOR OF TRACTOR DIESEL ENGINE (Fig. 194*a*). This is a four-pole series wound d.c. motor. It is more powerful than the motor described above and uses two additional electromagnetic relays B and C (Fig. 194*b*) which prevent the starter motor from being switched on when the engine is running.

The relay B has normally open contacts, whereas relay C has its contacts normally closed. The relay C is supplied from the a.c. terminals of the alternator and therefore it is equipped with a bridge rectifier built around four semiconductor diodes.

When starter switch *18* is turned on, the current from storage battery *21* is sent to the winding of the relay B, whose ground (return) circuit is completed through the contacts of the relay C. This causes the relay B to operate and energize the solenoid switch A of the starter motor. The motor is thus switched on to crank the engine.

As the engine picks up speed, the voltage supplied to the relay C from the alternator starts rising. As the voltage reaches 8 to 9 V, the relay C picks up and breaks its contacts, thus deenergizing the relay B. The spring pressure on the contacts of the relay B causes the



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Starter motor of tractor diesel engine

(a) construction;
(b) illustrating the operation of the starter motor;
1 – drive pinion;
2 – shifting lever;
3 – solenoid switch plunger;
4 – pull-in winding;
5 – hold-in (shunt) winding;
6 – contact disc;
7 – terminal contact and bolt;
8 – pull-in winding terminal bolt;
9 – battery wire terminal bolt;
10 – brushes;
11 – commutator;
12 – pole shoe;
13 – field-coil windings;
14 – armature;
15 – armature shaft;
16 – intermediate bearing;
17 – starter motor;
18 – starter switch;
19 – start interlocking switch (installed on transmission case);
20 – battery ground (master) switch;
21 – storage battery;
A – solenoid switch;
B – starting relay;
C – interlocking relay

contacts to open and switch off the starter motor.

With the engine running at any speed, the contacts of the relay C stay open and prevent the starter motor from being switched on.

STARTER MOTOR TROUBLES. The basic problems with the starter motor are as follows: the starter motor fails to crank; the starter motor cranks slowly; the drive pinion clashes and grinds when being meshed with the flywheel ring gear.

When you turn the ignition key to start and nothing happens, the first thing you probably think about is a dead battery. You might be right, but before you check the battery, turn on the headlights or dome light and try cranking. If the lights do not come on, either the battery is dead or a connection is bad. Check the connections at the battery, at the starter motor solenoid switch, and at the starter switch or relay. If the lights go out as you try to crank, there may be a bad connection at the battery. The bad connection lets only a small current through – enough for the lights to go on. But when you try to start, all the current goes to the starter motor because the motor has much less resistance than the lights. Therefore the lights go out. Try wiggling the battery connections to see if this helps. If the lights dim only slightly, the trouble probably is in the starter motor. Either the pinion is not engaging with the flywheel, or there is an open circuit inside the starter motor. If you hear the starter motor armature spin, then the overrunning clutch is slipping. If the lights dim heavily, this is most likely due to a run-down battery. Another cause of this trouble may be the seasure or dragging of the starter motor or the engine. If the starter motor does not crank, and the lights stay bright when you try to start, the trouble probably is either in the starter motor or in the circuit between the ignition switch and the solenoid switch. If the trouble is not in the wiring, then it is in the starter motor.

If the starter motor cranks slowly and the engine does not start, the trouble is probably due to a discharged battery. The battery does not have enough power to crank the engine fast enough for starting.

If the drive pinion clashes or grinds when meshing with the flywheel, the trouble is probably due to a faulty overrunning clutch assembly of damaged teeth on the pinion or the flywheel.

20.2. Lighting and Signalling Equipment

Lights have three important functions: they provide illumination for seeing at night, for being seen, and for signalling.

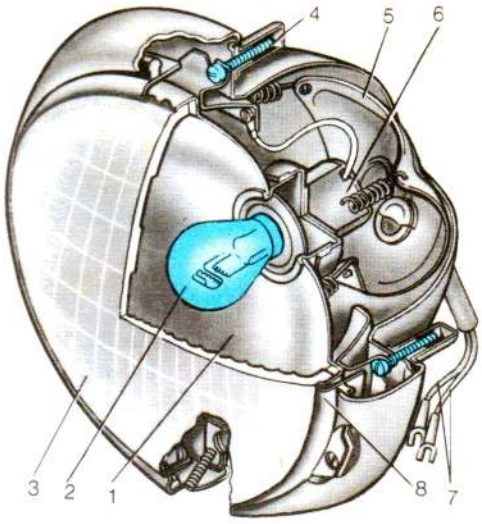
A complete automotive lighting system includes headlights, parking lights, side marker lights, stoplights, backup lights, taillights, hazard warning lights (turn signals), and interior lights. The interior lights include istrument panel lights, various warning and indicator lights, and dome lights. Included in the system are also various switches and wiring.

Automobiles may have two or four headlights at the front, whereas tractors are equipped with two headlights at the front and other two at the rear.

THE HEADLIGHT (Fig. 195) consists of body *5*, reflector *1*, lens *3*, retaining ring *8*, wiring assembly *7*, and lamp-holder (socket) *6* with lamp (bulb) *2*. The lens, reflector, and lamp make up what is known as the headlight insert. The insert is held to the retaining ring by spring clips, and the ring is attached to the headlight body by a screw. Besides, the headlight insert is attached directly to the body by springs and adjusting screws *4*.

The reflector concentrates the light into a forward beam. Its inside surface is polished and coated with varnish and a thin layer of aluminium or chrome. To reduce glare, the lens is designed to focus the beam so as to make it slant downward and produce an elliptical light spot. It therefore has a convex shape and is provided with glass prisms on the inside surface. The correct position of the lens is essential. Therefore, there is a mark on the lens that identifies its top.

The headlight can be aimed by changing the position of the headlight insert in the body with the aid of adjusting screws *4*, or by swiveling the



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Headlight

1 – reflector;
2 – lamp (bulb);
3 – lens;
4 – adjusting screw;
5 – body;
6 – lamp-holder (socket);
7 – wiring assembly;
8 – retaining ring

headlight body on its support, if a swivel-type support is used.

Automotive lamps (Fig. 196) may have one or two tungsten filaments contained in a glass bulb. Two-filament lamps are used in headlights, one filament for the high beam and the other for the low beam, and also in all kinds of combination lights. Some two-filament lamps have an internal shield which, in conjunction with the lens, helps direct the beam downward and to the right (European style) to reduce glare.

Lamps may be either vacuum or gas-filled type. Lights with a candle power of 3 cd and more are all gas-filled. The lamps are usually filled with some noble gas (argon, xenon, krypton) or a gas mixture (usually 96% argon and 4% nitrogen).

Side marker lights serve the purpose of making the overall dimensions of the vehicle discernable in conditions of poor visibility or at night. They are also used as turn signal lights. Marker lights must be visible from a distance of not less than 100 m.

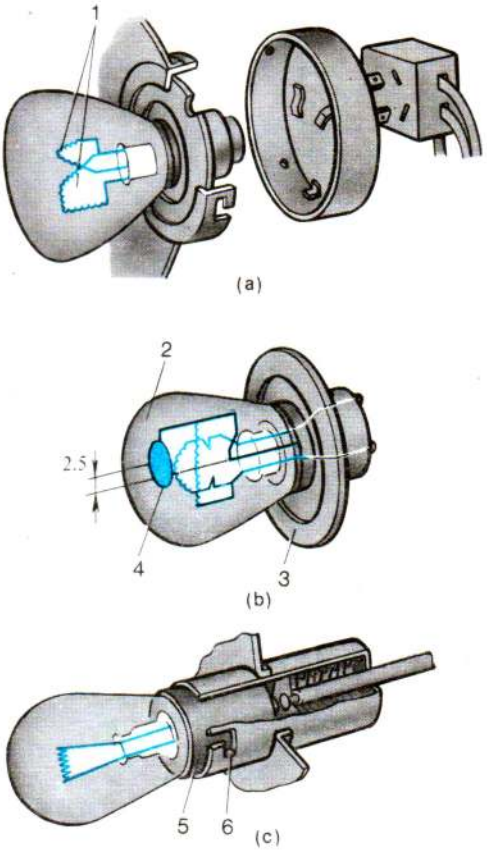
THE FRONT SIDE MARKER LIGHT (Fig. 197*a*) consists of body *3*, lens *6*, rim *7*, and two-filament lamp *4* held in socket *2*. The 21-cd filament of the lamp is used for the turn signal light and the 6-cd filament for the side marker light.

THE TAIL SIDE MARKER LIGHT (Fig. 197*b*) also doubles as a turn signal light and a stoplight. It consists of a body, a lens, and two lamps held in sockets. The body of the light is divided in half by a horizontal partition. The lower part of the body houses 3-cd lamp *10* which is used for the side marker light, parking light, and licence plate light. The upper part of the body contains 21-cd lamp *9* used for the turn signal light and stoplight.

Lenses *6* of the side marker lights are ruby-colored and are optically designed as reflex reflectors.

THE TURN SIGNAL (Fig. 198*a*) is intended to give a warning that the vehicle is about to make a turn. It includes turn signal lights, a turn signal switch, and a turn signal flasher. Most common are electromagnetic turn signal flashers. Such a flasher (Fig. 198*b*) consists of core *3* with winding *6*, two armatures 2 and 5, two pairs of silver contact points *1*, string *4* of a Ni-Cr alloy, and resistor *7*. Left-hand armature *5* carrying a contact point at its tip periodically inserts resistor *7* into and removes it from either of the two turn signal light circuits, thus making the lights flash, while right-hand armature *2*, which also carries a contact point, closes and opens as periodically the circuit of turn signal indicator lamp *9* located on the instrument panel in the driver's cab, which makes the lamp go on and off repeatedly.

Turn signal switch is mounted on the steering column. When the switch lever is moved either way from its neutral (center) position, the switch contacts close the circuit of the corresponding turn signal lights *11*. The current from the battery then flows through left-hand armature *5*, string *4*, resistor *7*, winding *6*, and turn signal lights to ground and returns to the battery. Since at this time all the flasher



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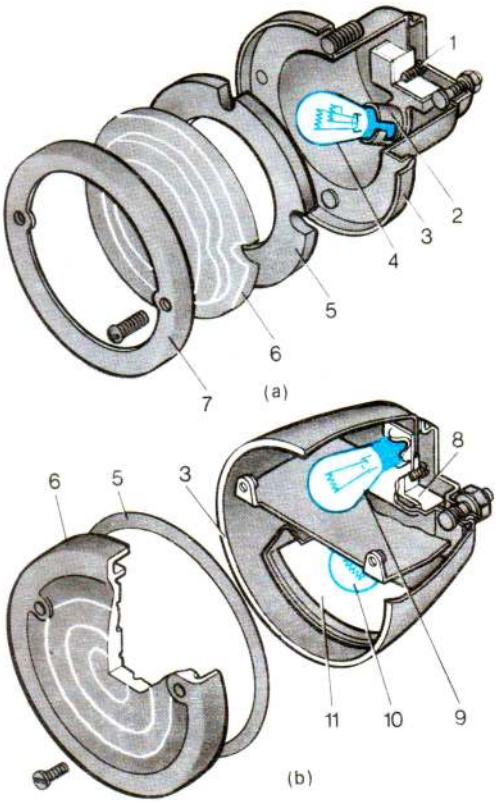
Automotive lamps

(a) two-filament lamp;
(b) two-filament lamp with internal shield;
(c) one-filament lamp;
1 – filaments;
2 – glass bulb;
3 – base flange;
4 – internal shield;
5 – base;
6 – retaining pin



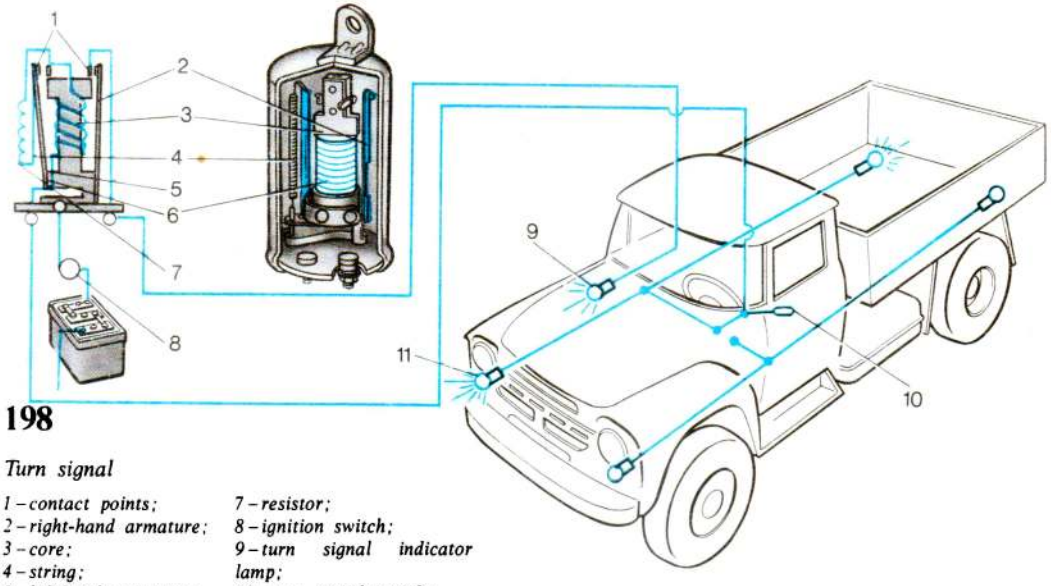
197

(a) Front and (b) tail side marker lights

1 – clamp;
2 – socket;
3 – body;
4 – lamp;
5 – rubber gasket;
6 – lens;
7 – rim;
8 – socket insulator;
9 – lamp for turn signal light and stoplight;
10 – lamp for side marker light and licence plate light;
11 – white lens

contacts are open, the current has to flow through the string (which has a relatively high resistance) and the resistor. This makes the turn signal lights dim.

As the current passes through string *4*, the string heats and extends. This allows the flasher core to attract the left-hand armature and close the left-hand set of contact points. With the contact points closed, both the string and the resistor are shorted out of the turn signal light circuit, and the turn signal lights flash bright. At the same time, the current through the flasher winding increases, so that the magnetic field produced by the winding becomes sufficient to attract the right-hand armature to its core. The armature closes the right-hand set of contact



198

Turn signal

1 – contact points;
2 – right-hand armature;
3 – core;
4 – string;
5 – left-hand armature;
6 – winding;
7 – resistor;
8 – ignition switch;
9 – turn signal indicator lamp;
10 – turn signal switch;
11 – turn signal light

points and the turn signal indicator lamp goes on.

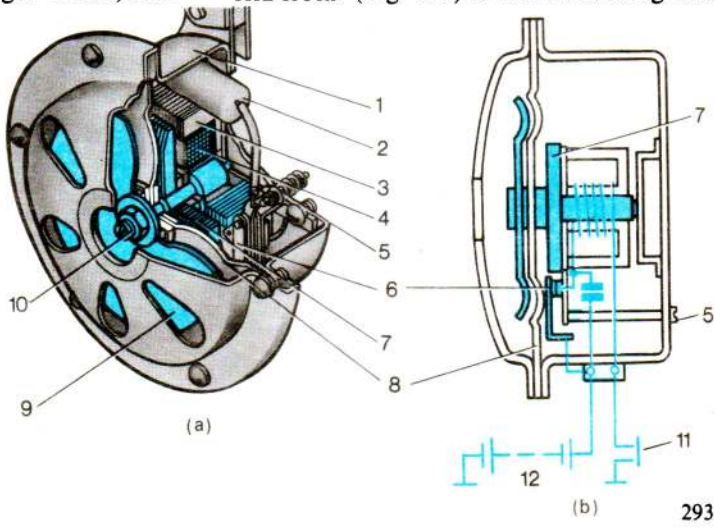
When the current ceases flowing through string *4*, the string cools off and contracts. As the string contracts, it forces the left-hand armature to break away from the flasher core and open the left-hand set of contact points. The resistor and the string are thus again inserted into the turn signal light circuit, and the lights dim. The current through the flasher winding is reduced, allowing the right-hand armature to move away from the core and open the right hand set of contact points. The turn signal indicator light goes off. The cycle is repeated again and again until the turn signal switch is turned off, the lights flashing 70 to 100 times a minute.

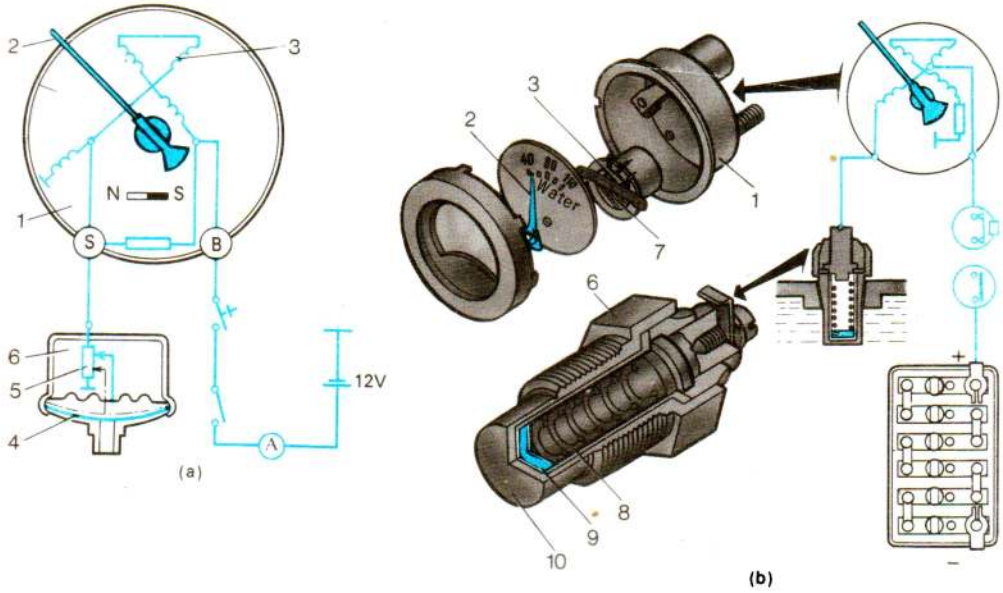
THE HORN (Fig. 199) is the electromagnetic

199

Horn

(a) construction;
(b) illustrating the operation of the horn;
1 – body;
2 – capacitor;
3 – core;
4 – field coil;
5 – adjusting screw;
6 – contact breaker;
7 – armature;
8 – diaphragm;
9 – resonator;
10 – central screw;
11 – horn button;
12 – power supply source





200

(a) Oil pressure and (b) coolant temperature indicators

1 – indicator;
2 – pointer;
3 – coil;
4 – diaphragm;
5 – rheostat;
6 – sender;
7 – permanent magnet;
8 – spring;
9 – thermistor;
10 – cartridge

vibrating type. It consists of body *1*, E-type core *3* with winding *4* (field coil), steel diaphragm *8*, armature *7*, and contact breaker *6*. The winding is connected across the battery terminal posts via horn button *11* located in the center of the steering wheel. When the horn is turned off, the contact breaker points are closed. Capacitor *2* placed in parallel with the contact points protects them against burning as a result of arcing.

When the horn button is depressed, current starts flowing through the field coil. This produces a magnetic field that pulls the armature together with the diaphragm to the right (in Fig. 199*b*). As the diaphragm moves right, it produces a click, and the contact points are separated, so that no current can flow. The magnetic field in the field coil collapses, and the diaphragm is released. It moves to the left with another click. This action is so rapid that the separate clicks blend to form the horn sound. The pitch of the sound can be adjusted by means of adjusting screw *5*.

20.3. Indicating Devices, Electric Motors, Fuses, and Circuit Breakers

Indicating devices serve the purpose of monitoring the operation of the various engine systems. These devices include oil pressure gauges, coolant temperature gauges, fuel gauges, ammeters, or charge indicators, oil pressure indicators, engine temperature indicators, and various warning lights. All these devices are arranged on the instrument panel in the driver's cab, while their senders are located at the strategic points about the engine and the vehicle.

THE OIL PRESSURE INDICATOR (pressure gauge) is designed to indicate the pressure of oil in the engine lubricating system. It consists of sender *6* (Fig. 200*a*) and indicator *1*. The sender consists of a chamber with diaphragm *4* and

rheostat *5*. The rheostat wiper is connected to the diaphragm. As the pressure in the lubricating system increases, the diaphragm deflects and moves the wiper of the rheostat, thus changing its resistance.

Electromagnetic indicator *1* consists of a shielded case which prevents stray magnetic fluxes from affecting the indicator readings, three coils *3*, moving permanent magnet with pointer *2* that can turn on an axle, and a stationary permanent magnet that permits zero-setting the indicator.

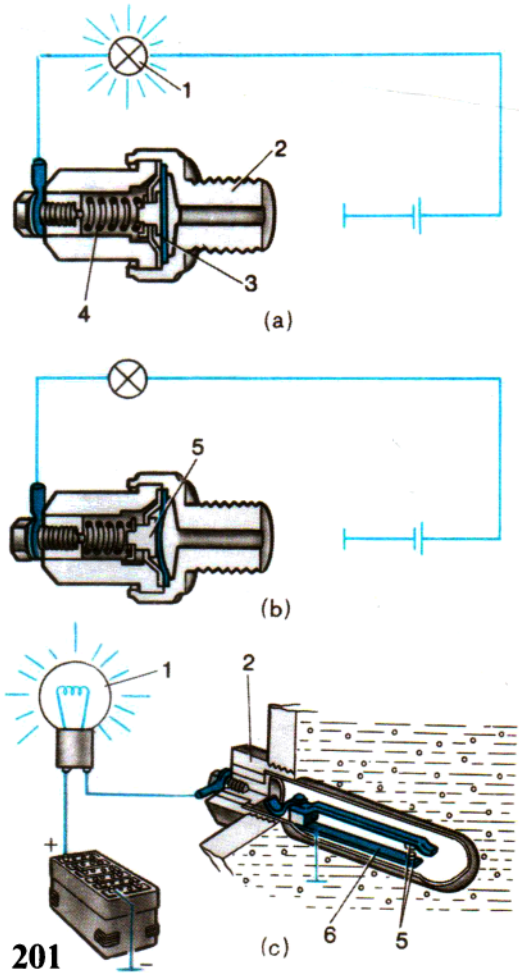
When current flows through the coils, the coils produce a resultant magnetic field which interacts with the field of the moving permanent magnet to set the indicator pointer in a position corresponding to the position of the rheostat wiper, which in turn corresponds to the oil pressure in the lubricating system.

THE COOLANT TEMPERATURE INDICATOR (Fig. 200*b*) is similar to the indicator described above.

The sender of the coolant temperature indicator comprises thermistor *9* (a semiconductor wafer) accommodated in metal cartridge *10*. The resistance of the thermistor varies in accordance with its temperature. Any change in the temperature of the coolant causes the resistance of the thermistor to change sharply. This causes a corresponding change in the current flowing through the coils of the indicator, hence in the resultant magnetic field produced by them. In response to this change, the permanent magnet turns and moves the pointer over the scale which is calibrated to read temperature.

WARNING (INDICATOR) LIGHTS are used to warn the driver that the engine is overheating and that the oil pressure in the engine lubricating system is too low. The lights are located on the instrument panel and are operated by their respective senders.

The sender of the oil pressure warning light (Fig. 201*a* and *b*) consists of body *2*, diaphragm *3*, spring *4*, and contact set *5*. When there is no pressure in the system, or when it is too low, spring *4* keeps the contacts closed (Fig. 201*a*), so that the warning light stays on. As the oil pressure grows higher, the diaphragm is forced



201

Warning (indicator) light senders

(a) and (b) oil pressure sender;
(c) engine temperature sender;
1 – warning (indicator) light;
2 – body;
3 – diaphragm;
4 – spring;
5 – contact set;
6 – bimetal strip

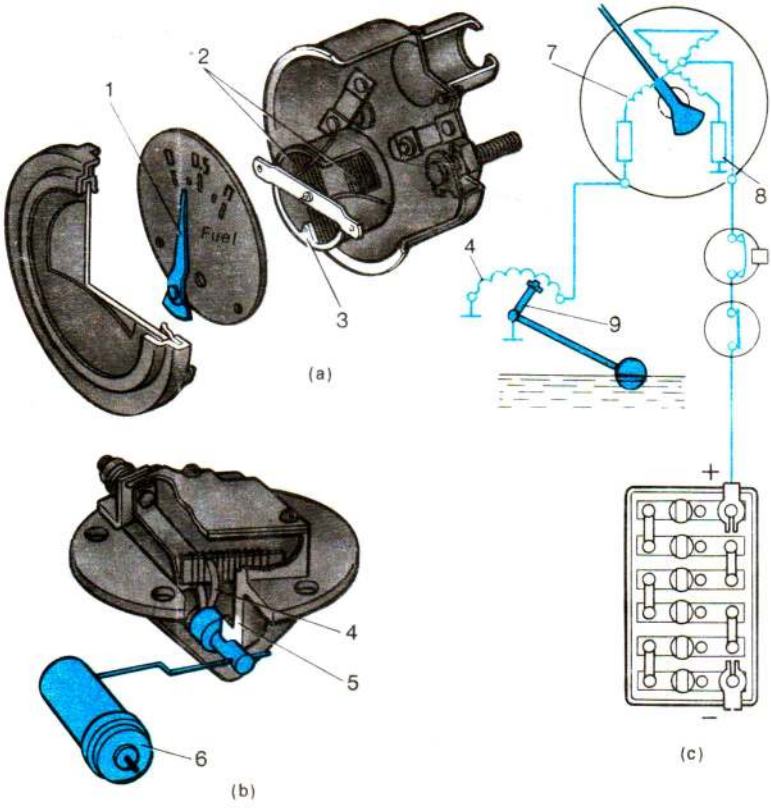
to deflect against the pressure of spring *4*. As soon as the oil pressure reaches its normal value, the diaphragm opens the contacts, and the light goes out (Fig. 201*b*).

The sender of the engine temperature warning light (Fig. 201*c*) is installed in the

202

Fuel level indicator

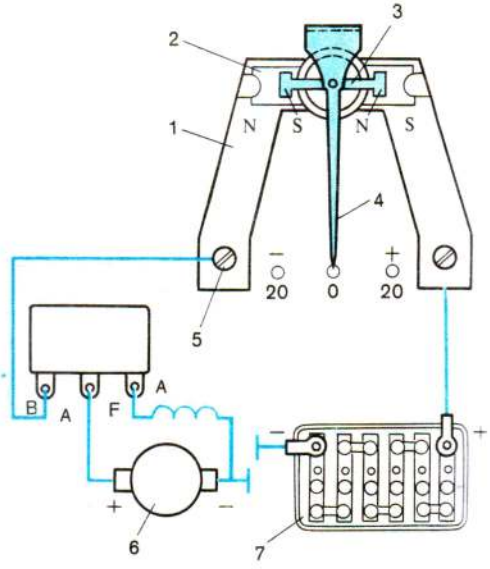
(a) indicator;
(b) sender;
(c) illustrating the operation of the indicator;
1 – pointer;
2 – coil;
3 – permanent magnet;
4 – rheostat;
5 – case;
6 – float and lever;
7 – left-hand coil;
8 – resistor;
9 – wiper

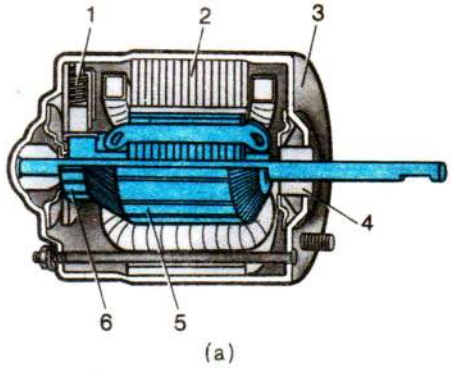


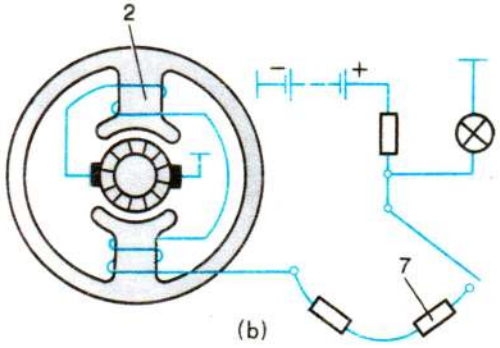
203

Ammeter

1 – flat brass conductor;
2 – permanent magnet;
3 – armature;
4 – pointer;
5 – terminal screw;
6 – generator;
7 – storage battery







204

Heater motor

(a) construction;
(b) illustrating the operation of the motor;
1 – brush;
2 – pole shoe with field coil;
3 – end shield;
4 – self-aligning bearing bushing;
5 – armature;
6 – commutator;
7 – variable resistor

header tank of the radiator. The sender consists of body *2* with a brass cartridge that houses two contacts *5*. The fixed contact is connected to ground. The moving contact is held to bimetal strip *6* which is connected to warning light *1*.

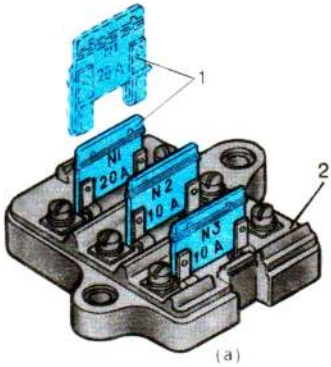
When the coolant temperature is normal, the sender contacts are open, but when it exceeds a preset value, the deflection of the bimetal strip is sufficient to close the contacts and turn the warning light on.

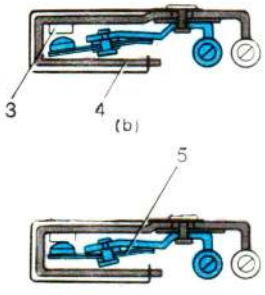
THE FUEL LEVEL INDICATOR (Fig. 202*a*) is similar in design to the oil pressure and coolant temperature indicators described above.

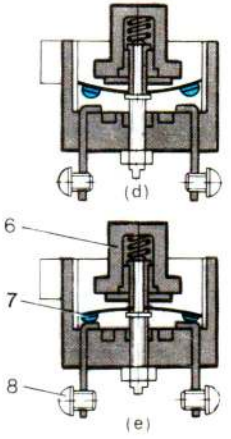
205

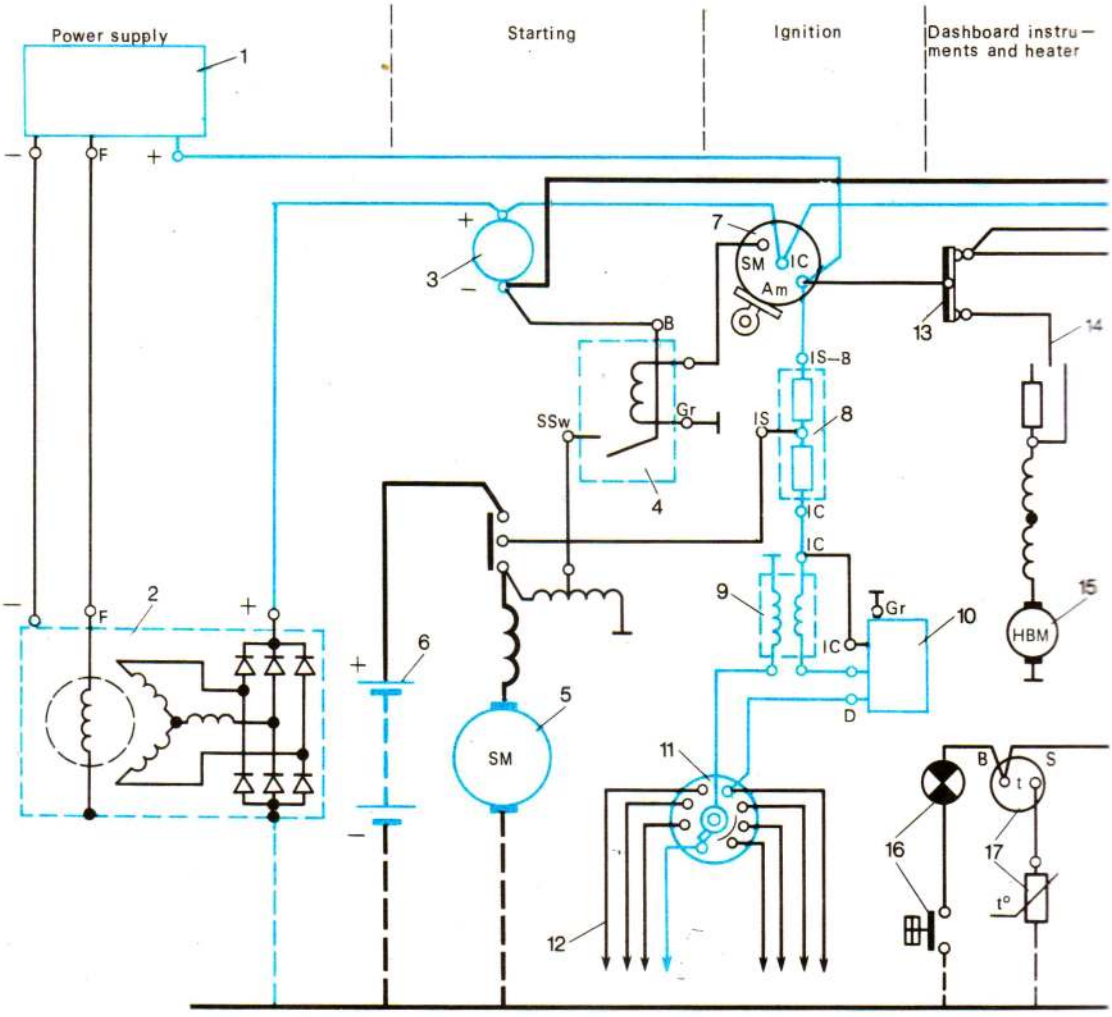
Fuses and thermal cut-outs

(a) fuses;
(b) and (c) multi-shot thermal cut-out;
(d) and (e) single-shot thermal cut-out;
1 – fuse;
2 – fuse panel;
3 – fixed contact point;
4 – body;
5 – bimetal strip;
6 – push button;
7 – bimetal strip;
8 – terminal screw







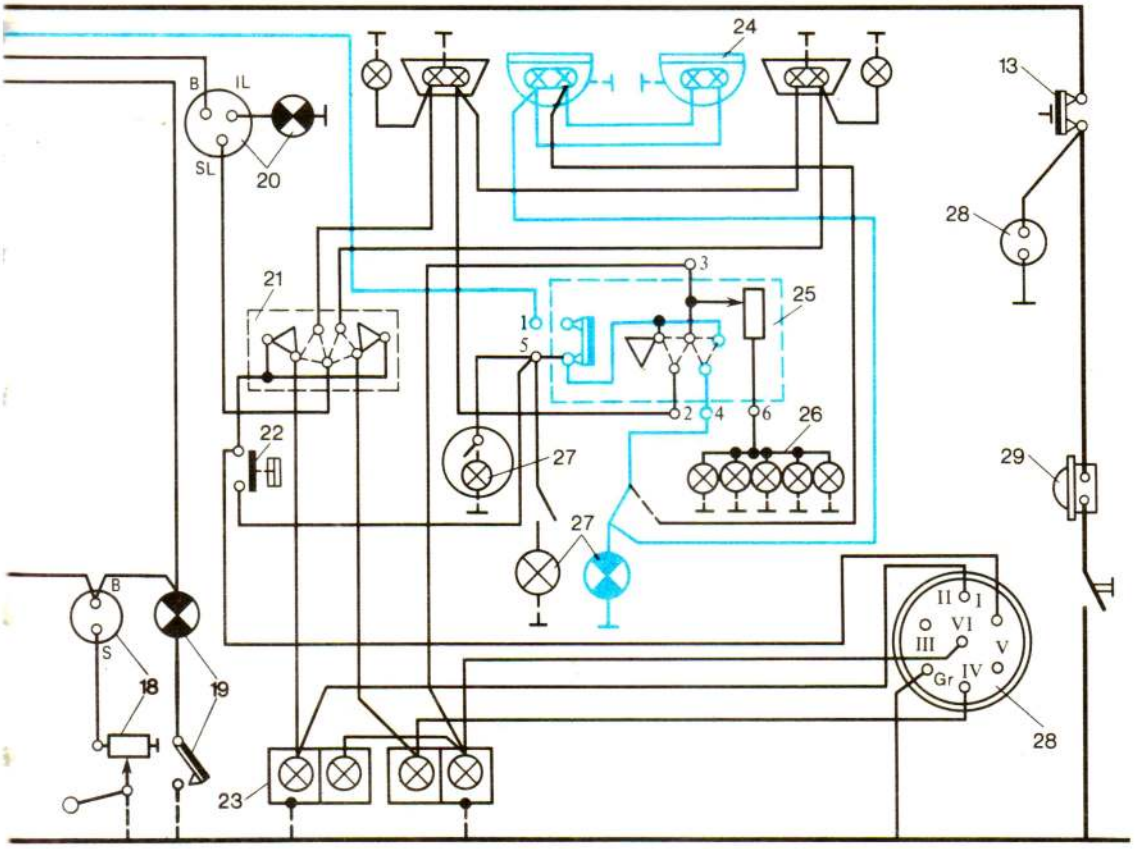


The fuel level indicator sender (Fig. 202*b*) is a rheostat housed in metal case *5*.

The resistance of the rheostat changes in accordance with the fuel level in the tank because its sliding contact (wiper) is connected to the lever that carries float *6* on its end. The current flowing through the left-hand coil (Fig. 202*c*) of the indicator, hence the magnetic field produced by the coil, depends on the position of rheostat wiper *9*. When the fuel tank is full, the resistance of the rheostat is at its maximum, and the current in the left-hand coil is at its minimum. In this case, the resultant magnetic field of all the indicator coils causes the pointer to align itself with the mark П (meaning "full" in Russian).

As the fuel level in the tank drops, the current in the left-hand coil increases, with the result that the pointer moves over the scale toward the zero mark. Resistor *8* provides for temperature compensation.

THE AMMETER (Fig. 203) serves the purpose of monitoring the charging of the battery and the operation of the alternator. The ammeter is



206

Automobile wiring diagram

1 – alternator regulator;
2 – alternator;
3 – ammeter;
4 – solenoid switch;
5 – starter motor;
6 – storage battery;
7 – ignition switch;
8 – series resistors;
9 – ignition coil;
10 – solid-state commutator;
11 – ignition distributor;
12 – spark plug;
13 – thermal cut-out;
14 – heater motor switch;
15 – heater motor;
16 – oil pressure warning light and oil pressure indicator contact;
17 – water temperature indicator and sender;
18 – fuel level indicator and sender;
19 – water temperature warning light and sender;
20 – turn signal flasher and turn signal indicator light;
21 – turn signal switch;
22 – stoplight switch;
23 – taillights;
24 – headlight;
25 – main light switch;
26 – instrument cluster light;
27 – cowl, dome, and high beam indicator lights;
28 – female connector;
29 – horn

always connected in series in the circuit where the flow of current is to be measured. It consists of flat brass conductor *1*, permanent magnet *2*, armature *3* carried on an axle, pointer *4*, and a scale. The pointer is fixed to the axle.

When the conductor carries no current, the armature is disposed along the magnet, so that the pointer is set opposite the zero mark in the center of the scale. When current flows through the conductor, a magnetic field is produced around it. The armature now aligns itself with the lines of force of this field, causing the pointer to turn through a certain angle. The magnitude of the angle through which the pointer turns depends on the magnitude of the current flowing through the conductor, and the direction in which the pointer turns is governed by the direction of the current through the conductor. If the pointer deflects toward the + + sign, the current is flowing to the battery and the battery is being charged. If the pointer deflects the other way, the current is flowing from the battery, i. e., the battery is discharging.

Automotive electrical systems use d.c. motors to drive fans, windshield wipers, etc.

Two-pole series-wound motors (Fig. 204) are most common. The principal components of such a motor are the stator with pole shoes *2* that carry the field coils, wound armature *5*, and commutator *6*. The armature and commutator are rigidly fixed on a shaft that is supported by plain bearing bushings housed in end shields *3*. The motor shown in Fig. 204 is used to drive the heater blower. Therefore, it is connected to the power supply source through variable resistor *7* which enables one to change the motor speed.

FUSES AND THERMAL CUT-OUTS (circuit breakers) (Fig. 205) are used to protect the components of automotive electrical systems against short-circuit currents and overloads. Fuses are assembled into a panel that is mounted on the instrument panel. Each fuse *1* (Fig. 205*a*) is numbered and protects a circuit of its own.

Automobiles also use thermal cut-outs in addition to the fuses. Such cut-outs may be of multi-shot type, in which case they are frequently referred to as circuit breakers, and of single-shot type.

Multi-shot thermal cut-outs, or circuit breakers, are mainly used to protect lighting equipment circuits. The cut-out (Fig. 205*b* and *c*) consists of body *4* and bimetal strip *5* carrying a contact point at its end. The cut-out is designed to carry no more than 20 A. The contact point on the bimetal strip is pressed against a stationary contact point held to the body of the device. Consequently, the contact points are normally closed.

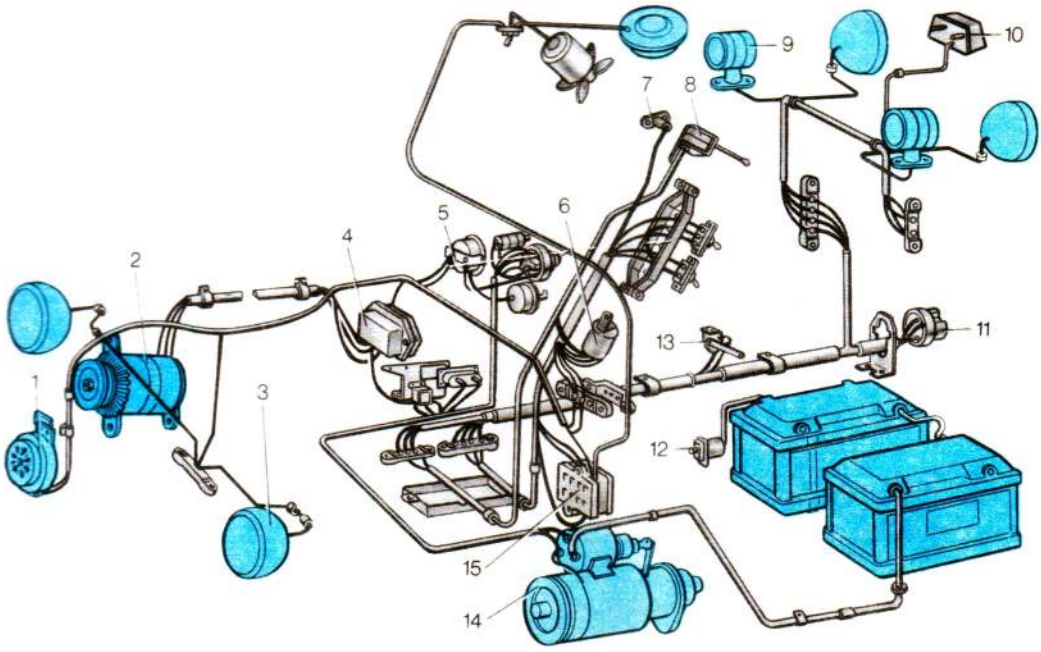
If the current flowing through the bimetal strip should exceed the preset value, the strip will get hot enough to deflect and open the contact points (Fig. 205*b*), thus opening the circuit. The current ceases flowing and the strip cools off. As the strip cools, it straightens out until, in the end, the contact points touch and close the circuit again (Fig. 205*c*). If the shorted condition still exists, the cycle repeats itself. causing a clicking sound.

The single-shot thermal cut-out (Fig. 205*d*) is a push-button type. It consists of a body with built-in contact points and bimetal strip *8*. In case of overloads, the strip deflects and opens the contact points. To reset the cut-out, it is necessary to depress push button *6* (Fig. 205*e*).

20.4. Wiring System

Electrical equipment of modern tractors and automobiles is a complex system of numerous electrical components interconnected by a multitude of wires making up a system of their own. To help the mechanic trace and service the wiring system, use is made of wiring diagrams similar to the one shown in Fig. 206. To facilitate the reading of the diagram, the components making up the most important subsystems, such as the power supply (charging), starting, ignition, instrumentation. signalling, and lighting system components, are shown here gathered into individual groups. In actual fact, there is no such grouping, as is readily seen from Fig. 207.

All tractors and automobiles manufactured in this country use one-wire systems in which the vehicle frame and other metal parts are



207

Tractor wiring layout

1 – horn;
2 – generator;
3 – headlight;
4 – generator regulator;
5 – ammeter;
6 – turn signal;
7 – horn button;
8 – turn signal switch;
9 – side marker light;
10 – licence plate light;
11 – female connector;
12 – battery ground (master) switch;
13 – stoplight switch;
14 – starter motor;
15 – fuse box

employed as the second (ground, or return) wire. One-wire systems are simpler and less expensive than their two-wire counterparts, but require very careful handling and systematic inspection of the condition of wiring insulation, for even a single ground fault here presents real fire hazard.

The direction of current flow is taken to be in accord with the conventional theory, i. e., current is assumed to be flowing from the positive terminal of the storage battery or alternator and through insulated wires to loads, and then to the negative terminal of the battery or alternator via the ground wire (the frame).

To facilitate the laying out of the wires and to provide for better protection, individual wires are taped together in bundles. The wires are color coded in order to facilitate their tracing in the bundles. Wire ends are equipped with lugs or connectors, which makes it easier to connect the wires to the various electrical system components.

The point of connection to the power supply sources is essential. The principle here is to connect directly to the battery only such components as draw much current and operate for a short period only (e. g., the starter motor, cigar-lighter) and also those which must be operable in emergency situations (e. g., the horn, cowl light, inspection lamp). The other loads are connected to the alternator. In this case, the loads are connected as dictated by the character of their operation: connected directly to the alternator are such loads as draw little current and operate for a long period of time; the loads that are operative only when the

engine is running are connected through the ignition switch; all the lighting equipment is energized through the main light switch.

WIRING SYSTEM TROUBLES. The most common problems with the wiring system are open circuits, short circuits, and ground faults. Open circuits may be caused by loose, badly corroded, or soiled connections, or by broken wires. Short circuits and ground faults are primarily due to damaged wiring insulation.

Review Questions

1. What is the difference between the starter motors used for starting i.c. starting engines and those used for starting tractor diesel engines directly?
2. What signalling devices do you know?
3. How can the headlight beam be aimed?
4. How is the tail side marker light constructed?
5. Referring to Fig. 198, explain the operation of the turn signal.
6. How does the horn operate?
7. What indicators do you know?

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Design of Automotive Engines

A. KOLCHIN, Eng., and V. DEMIDOV, Cand. Sc. (Eng.)

The book provides all the necessary information on the design of automobile and tractor engines and gives systematized calculation procedures involved in the design of such engines. Interrelations among heat calculations and dynamic analysis calculations, strength calculations of engine components, and the design of engine systems are revealed through exemplary comprehensive calculations pertaining to the design of carburettor and supercharged Diesel engines. It also presents an analysis of theoretical engine cycles and methods of controlling toxic engine emissions and outlines the design of supercharger units, shockless cams, and fuel systems. Much space is devoted to heat calculations of carburettor and Diesel engines, and computer-aided calculations of theoretical engine cycles are described.

Though intended primarily for college students, the book may also be of interest to automotive engineers.

Contents. The Fuel and Chemical Reactions. Theoretical Cycles of Piston Engines. Real Engine Cycle Calculation. Engine Heat Calculations and Heat Balance. Engine Speed-Torque Characteristics. Kinematics of Crank Mechanism. Dynamics of Crank Mechanism. Engine Balancing. Engine Kinematic and Dynamic Analysis Calculations. Engine Design Premises and Design Operating Conditions. Piston Assembly Design. Connecting Rod Assembly Design. Crankshaft Design. Engine Body Design. Timing Gear Design. Engine Supercharging. Design of Fuel System Elements. Design of Lubricating System Elements. Design of Cooling System Elements.